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Linda L. Huff

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The benefit-cost analysis presented in this report identifies the primary activities affected by changes in water quality, namely, fishing. By estimating the recreational fishing value of the existing stock of rivers impacted by the cyanide dischargers, and approximation of the recreational loss sustained by changing the cyanide standard can be made. Although this analysis certainly does not include all possible benefits, it is considered a close approximation. Treatment costs for the discharger provide the balancing factor in determining feasible effluent levels.

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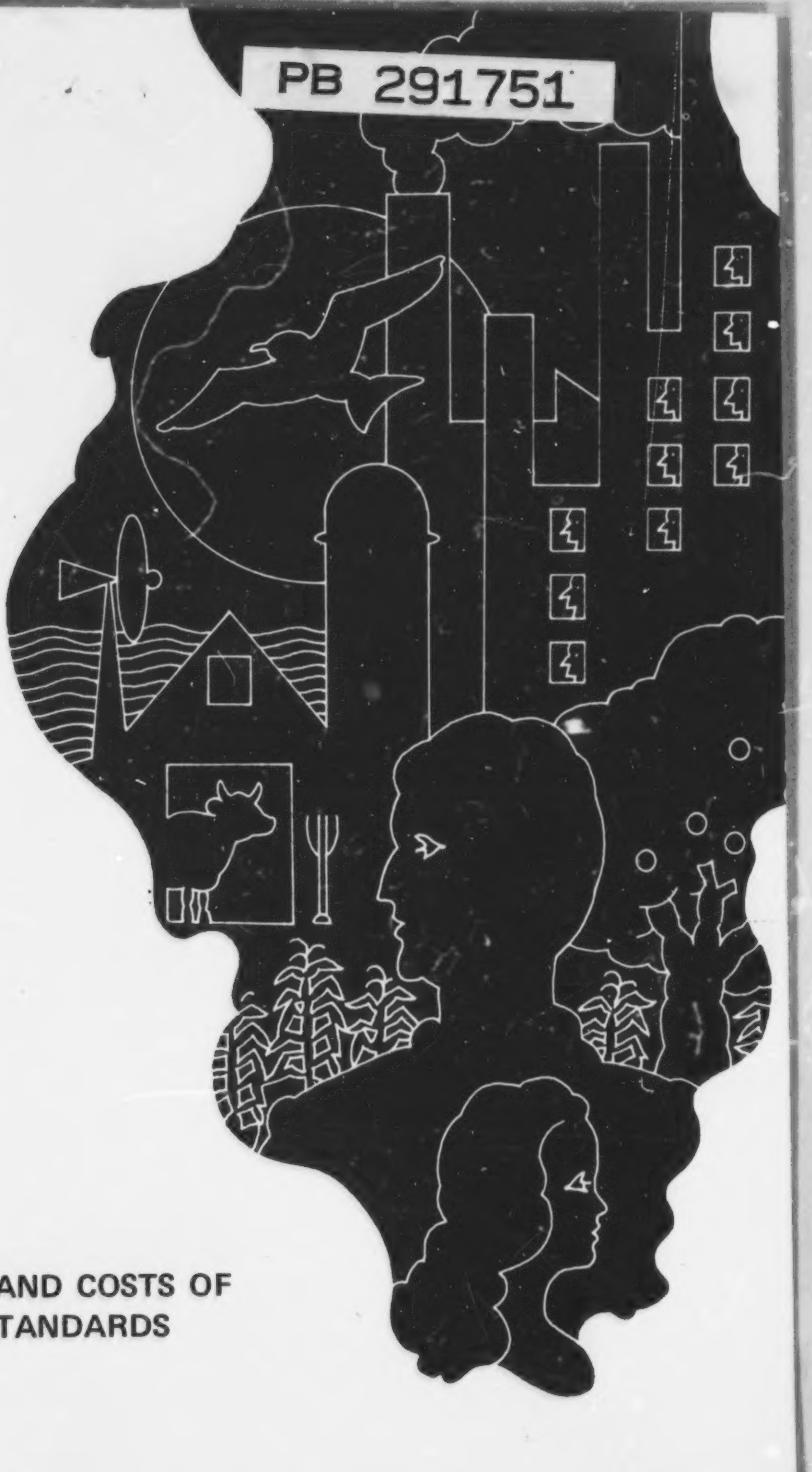

ANALYSIS OF THE BENEFITS AND COSTS OF ALTERNATIVE CYANIDE STANDARDS IN ILLINOIS

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ANALYSIS OF THE BENEFITS AND COSTS OF ALTERNATIVE CYANIDE STANDARDS IN ILLINOIS

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This report was prepared for the

Illinois Institute for Environmental Quality

by

Linda L. Huff
Associate Economist/Engineer

James E. Huff
Associate Environmental Engineer

IIT Research Institute

STATE OF ILLINOIS
INSTITUTE FOR ENVIRONMENTAL QUALITY
Dan Walker, Governor
Samuel G. Booras, Director

November, 1975

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FOREWORD

The formulation of this project began during July, 1975; and the original scope of work was designed to review the existing Illinois cyanide effluent standard (Rule 408a) and the existing Illinois cyanide water quality standard (Rule 203f).

In addition, Public Act 79-790 (Senate Bill 805), which became effective October 1, 1975, requires that an economic impact study be prepared for regulations proposed before the Illinois Pollution Control Board. This report will be submitted officially to the Illinois Pollution Control Board as an economic impact study of proposals R74-15 and R74-16, now pending before the Board.

This publication, therefore, fulfills the need for review of the existing cyanide effluent standards as well as the need to provide an economic impact study for review of pending proposals R74-15 and R74-16.

The Institute solicits your comments and criticisms of this report.

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Chapter 1

INTRODUCTION

Water and air are properties shared by firms and citizens but there is no monetary cost for using or damaging these properties. As a result, pollution can be considered an external effect * which is difficult to value. That is, when a discharger upstream adversely affects downstream users or consumers, then that discharger has created external effects.

This inflicted damage cost is not reflected in the upstream discharger's cost or revenue function, and therefore he does not adjust for the downstream problems. These unconsidered costs may result in a misallocation of resources. To achieve an efficient solution the discharger must consider these pollution costs in his cost function or, in other words, the costs must be "internalized".

There are many methods utilized by government agencies to internalize the costs of pollution to producers of pollution and thereby achieve satisfactory water quality. Three accepted practices are listed below which have been applied in many states:

- effluent regulation (concentration limits)
- effluent regulation (pounds discharge limited by production)
- water quality maintenance by allocation of water discharges

Each regulating mechanism contains imperfections which result in non-optimal standards in the sense that the costs may not be distributed effectively among the dischargers and that the benefits associated with a standard may not sufficiently justify the costs incurred in obtaining a particular level of pollu-

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* An external effect occurs when the activities of one economic entity have a direct impact on the production or preference function of an independent entity.

tion. There may be a producer of pollution who could reduce his discharges by simple and cheap treatment compared to other neighbors. Standards do not allow any ordering of discharge controls based on cost per pound of pollutant removed; however, the use of standards does allow the evaluation of the total costs and benefits associated with any particular regulation. This report focuses upon the estimation of such values for specific proposed effluent regulations.

The present total cyanide effluent standard in Illinois is 0.025 mg/l, not to be exceeded in any 24-hour composite sample. Thus, using the strict interpretation of the effluent standard, any discharger exceeding that level for any 24-hour period is in violation of the standard. Modifications of this regulation have been proposed by the Illinois Petroluem Council, and Republic Steel. The versions which have been proposed for adoption are summarized below.

	Cyanide Regulation Proposed	
Proponent	Simple Concentration (mg/l)	Total Concentration (mg/l)
Illinois Petroleum Council	0.1	--
Republic Steel	0.1	2.0

To evaluate the merit of these proposals, one must comprehend the economic significance of the existing and proposed regulations. The economic justification of a standard can be measured by examining the benefits and costs associated with the standard.

The economic evaluation contained herein examines the magnitude of the existing cyanide problem within the State of Illinois. Those receiving streams and dischargers in violation of the standards are carefully described as to location, quantity, and extent of the violation detected. From this information, it is possible to determine the treatment needs and costs associated with the existing regulation and its proposed modifications. These costs are then utilized in a benefit-cost analysis.

The benefit-cost analysis presented in this report identifies the primary activities affected by changes in water quality, namely, fishing. By estimating the recreational fishing value of the existing stock of rivers impacted by the cyanide dischargers, an approximation of the recreational loss sustained by changing the cyanide standard can be made. Although this analysis certainly does not include all possible benefits, it is considered a close approximation. Treatment costs for the dischargers provide the balancing factor in determining feasible effluent levels.

From the delineation of the cyanide problem within the State of Illinois and an examination of the benefit-cost analysis, valuable information is gained. Not only is a concise description of the situation provided, but also an insight as to the appropriate effluent level.

Chapter 2

EXECUTIVE SUMMARY

The objective of effluent and water quality standards is protection of the rivers and streams and their biota. In ascertaining the appropriate level of regulation, the economic ramifications of such requirements must be considered. Modifications to the present cyanide effluent standard have been proposed by the Illinois Petroleum Council and Republic Steel. The petitioners are seeking a two-tiered standard with total and simple cyanide effluent restrictions. The specific effluent limits proposed by these groups are summarized below.

Proponent	Proposed Effluent Cyanide Regulations	
	Simple Concentration (mg/l)	Total Concentration (mg/l)
Illinois Petroleum Council	0.1	---
Republic Steel	0.1	2.0

In determining an appropriate standard based on a benefit-cost analysis, the magnitude of the existing problem had to be delineated. Although there were four major segments found to be discharging cyanide in Illinois (steel producing, petroleum refining, platers, and municipalities), the analysis of all Illinois EPA data indicated that this problem was not limited to these. Seventy dischargers in 10 categories were found to have cyanide discharge violations. As shown in Table 2-1, the municipalities represented the largest group of violators at 31. Other groups, although not normally identified as cyanide dischargers, were found to violate the existing effluent standard. These included chemical, stone, glass, and utility dischargers.

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Table 2-1

SUMMARY OF CYANIDE VIOLATORS

SIC	SIC Description	Total Number Reporting Values > 0.025 mg/ℓ
28	Chemical	10
29	Petroleum Products	1
2911	Petroleum Refining	4
32	Stone, Glass	1
33	Steel Manufacturing	9
34	Metal Treating and Fabrication	5
35	Metal Treating and Fabrication	1
4911	Electric Utilities	1
	Sanitary Districts	31
	Miscellaneous	7
	Total	70

The location of these dischargers in the state was important to the analysis because a concentration of cyanide dischargers could be expected to affect water quality more in the aggregate than isolated individuals. The Illinois and Des Plaines Rivers had 12 and 11 dischargers, respectively, which could be expected because of the concentration of industry in the Chicago metropolitan area. The Fox River was third with 9 dischargers, primarily sanitary districts. The Chicago-Calumet River area had only 7 but the volume of these discharges was significant. Therefore, this was considered an important area. There are also cyanide dischargers in ten other waterways, but not as concentrated as in the above three waterways.

Water quality problems are closely associated with the quantity of cyanide discharged from sources in close proximity. Of the 25 water segments which IEPA reported as violating water quality standards, 16 of these, or over 60%, were in Cook County. DuPage and Will Counties accounted for 3 additional violated segments and the rest were scattered across five counties. It thus appeared that the water quality problem as well as the cyanide discharger groups represented primarily the metropolitan Chicago area. In evaluating the costs and benefits of regulation, this area provided the basis for the analysis because of its significance.

As stated previously, four major groups were identified as discharging cyanide to Illinois waterways. A general characterization of the refining, steel, plating, and municipal dischargers provided a basis for estimating treatment costs, and they are summarized in the following paragraphs.

The major source of cyanide in a refinery is attributed to the catalytic cracking unit. The cyanide generation fluctuates widely in day to day and month to month operation. For example, the monthly average discharge for three refineries and the associated standard deviations are presented below.

Refinery	Month Average Effluent Concentration mg/l Total CN^-		Standard Deviation mg/l Total CN^-
Mobil	0.176	±	0.131
Union	0.098	±	0.090
Shell	0.045	±	0.031

The wide fluctuation in cyanide levels has resulted in effluent violations for all eight refineries in Illinois during the last 18 months. The average quantity of cyanide discharged per refinery ranges from 0.1 lbs per day for Clark up to 3.8 lbs per day for Mobil. Of course, the impact of these discharges depends upon the flow and condition of the receiving streams.

Another important discharge group is the steel industry. Their cyanides are generated during two activities, blast furnace operation and by-product coking. Hydrogen cyanide gases emitted during these operations are scrubbed and cooled with water which creates the resulting pollution problem. Like the refineries, there is a wide fluctuation in the cyanide levels generated in the blast furnace and coke plant operation which makes control difficult.

There are four steel plants in Illinois with cyanide discharges. Granite City Steel, which discharges to Horseshoe Lake, is in compliance on the average but has occasional violations. The other three companies are located in the Chicago area and their wastewater streams are directed to MSDGC's Calumet plant and the Calumet River. Because the Calumet plant of MSDGC violates the existing effluent standard, the coke wastes from all plants may require additional treatment. Wisconsin Steel's and Republic's discharge to the Calumet River is in violation of the existing standard although Republic Steel will cease discharge to the river as of December, 1975.

The municipal districts which are important cyanide dischargers do not generate cyanides but rather receive industrial wastes containing such materials. There are many activities which utilize cyanide, such as photography, dyes, engraving, etching, and plating, and these contribute to municipal cyanide loadings. Fourteen of the 31 municipal violators actually average less than 0.025 mg/l and their violations may be due to the lack of precision of the analytical test procedure. Of the remaining 17, nine municipal plants in the Chicago area violate the present standard, including three of MSDGC's plants. West-Southwest and Calumet are by far the largest cyanide dischargers at 269 and 117 lb per day, respectively. The cyanide loadings drop to less than 20 lb per day for the remaining dischargers. Reduction of cyanide at these plants can only be accomplished by stringent sewer ordinances to reduce the quantity of cyanide received.

The plating industry in Illinois is a group which is affected by the effluent limitations and municipal sewer requirements. Cyanide is utilized in plating baths, such as copper and zinc. Although the concentrated baths are not discharged as wastewater, overflows, spills, and leaks may result in high concentrations of cyanide in their effluents. There are five plating companies that are direct dischargers in Illinois who are presently not in compliance based on IEPA 1974-1975 data. The average effluent concentration varies from 0.082 to 1.173 mg/l for this group, which is considerably above present standards. The need for additional treatment at any standard is evident by the average and maximum cyanide levels experienced by this group.

In order to properly assess the impact of cyanide discharges on the receiving stream, one must determine its fate in the water. Cyanide appears to be a degradable substance based on MSDGC's reports of cyanide reduction across their treatment plant and other reports of biological treatment. Using four case studies of water quality, an estimation of the decay rate of cyanide was made. A cyanide spill reported in Dunreith, Indiana, a U.S. EPA Illinois River study, a U.S. EPA Chicago River study, and a MSDGC Chicago River study provided four estimates of a first order decay rate, which were 0.35, 0.14, 0.11, and 0.12 days^{-1}, respectively. Using a value of 0.12 for the decay rate, the impact of various loadings upon the receiving stream was determined.

Several factors were important in developing the benefit-cost analysis of cyanide regulation. Alternative standards for evaluation, toxic concentrations in the streams, treatment technology, and methodology for benefit analysis were all criteria utilized in an economic evaluation of standards. The determination of each aspect as it relates to the final analysis is described briefly herein.

The toxic concentrations of cyanide were important in selecting the standards to be evaluated and the effects of these standards on water quality. From the data collected during R74-15, R74-16 Regulatory Hearings, levels at which acute and chronic effects occurred were selected as 0.10 mg/ℓ and 0.025 mg/ℓ simple cyanide, respectively. Hydrocyanic acid (HCN), which is the most toxic species, is typically a large fraction of the simple cyanide analyzed, and thus the levels of 0.10 mg/ℓ and 0.025 mg/ℓ simple cyanide reflected similar HCN concentrations. The concentration range selected for effluent standards was based on the above chronic and toxic concentrations, and the existing cyanide levels found in both municipal and industrial discharges. The five alternative effluent standards which were evaluated are listed in Table 2-2.

Table 2-2

ALTERNATIVE EFFLUENT STANDARDS CONSIDERED

Cyanide Concentration Limit	Sample Type
0.025 mg/l total	24-hr maximum
0.025 mg/l total	monthly average
0.050 mg/l total	monthly average
0.10 mg/l total	monthly average
0.20 mg/l total	24-hr maximum

To measure the benefits associated with various levels of regulation, a method for determining the value of water quality was needed. By evaluating the recreational value of the fishing activity in three river basins, the benefits of improved water quality were measured. The recreational value was determined through the following methodology:

1) number of river fishing trips projected for planning area,

2) allocation of fishing trips per county by using a number of miles -- fish diversity index,

3) cost per fishing trip determined,

4) recreational value per stream mile determined by cost per trip multiplied by trips per mile in county.

Each standard is associated with a different probability of damage, and by using curves of probability versus damage, which is measured as lost recreational value, the benefits of each regulation were determined. Depending upon stream conditions and effluent variation, different levels of cyanide are present in these waterways. The probability of damage occurrence is related to the probability of stream flows and effluent loadings. With each standard, the quantity of cyanide varies, and thus different damage curves can be drawn for each standard. The incremental areas between these curves for each effluent regulation measured the benefits to be gained. For the three river basins studied, the Fox River, Chicago-Illinois Rivers, and Calumet River-Cal Sag Channel, the benefits are summarized in Table 2-3. These benefits represent the improvement of water quality over a totally unregulated condition, assuming a complete loss of fishing activity if cyanide were unregulated.

The costs to achieve these levels of benefits must be considered in the final evaluation of effluent standards. Treatment technologies were defined for each discharger group, depending upon their waste characteristics. Common methods of treatment included equalization, waste stream segregation, and ozone plus ultraviolet radiation. In Table 2-4 the annual costs of compliance are summarized by river basin and effluent standard. The highest costs are those on the Calumet River-Cal Sag Channel at $3,100,000. For the same standard, the cost is only $301,000 on the Fox, which indicates the wide range of treatment requirements.

The treatment costs were also estimated for the four major discharger groups. Table 2-5 contains the capital investment requirement by industry and Table 2-6 presents the annualized cost of compliance for the various standards. The total capital investment to bring all dischargers into compliance with the existing standard is approximately $27,500,000 or a $5,000,000 annual cost. The smallest compliance costs were associated with the 0.10 mg/l monthly average standard and were only $1,510,000 capital investment and $230,000 annual costs.

The benefit-cost analysis combines the information obtained to ascertain the appropriate level of regulation. The ratio of benefits to costs is not important at this point but rather the marginal benefit and cost curves. In order to maximize net benefits, it is important to compare the incremental or marginal effects of additional costs. Where the marginal benefits and costs intersect, the maximum net benefit is achieved.

Table 2-3

ANNUAL BENEFITS OF PROPOSED EFFLUENT STANDARDS

Effluent Standard (mg/ℓ total cyanide)	Incremental Benefits Over Unregulated Conditions*		
	Fox River	Chicago-Illinois River	Calumet River-Cal Sag Channel
Total Recreational Value of Stream	$1,500,000	$670,000	$92,000
0.025 -- 24-hr maximum	1,500,000	670,000	92,000
0.025 -- monthly avg.	1,500,000	641,000	90,000
0.050 -- monthly avg.	1,474,000	625,000	81,000
0.10 -- monthly avg.	1,430,000	556,000	12,000
0.20 -- 24-hr maximum	1,490,000	625,000	44,000
Existing Conditions	1,430,000	556,000	12,000

* Unregulated conditions assumes complete annual fish kill.

Table 2-4

SUMMARY OF ANNUAL COMPLIANCE COSTS FOR THREE RIVER SYSTEMS

Effluent Standard (mg/ℓ total cyanide)	Annual Costs (dollars)		
	Fox River	Chicago-Illinois River	Cal Sag Channel
0.025 -- 24-hr maximum	$301,000	$1,230,000	$3,100,000
0.025 -- monthly average	173,000	1,100,000	2,750,000
0.050 -- monthly average	114,000	310,000	1,540,000
0.10 -- monthly average	10,000	140,000	0
0.20 -- 24-hr maximum	129,000	210,000	0

Table 2-5

CAPITAL INVESTMENT REQUIREMENTS FOR COMPLIANCE WITH VARIOUS STANDARDS

Effluent Standard (mg/ℓ cyanide)	Capital Investment of Industry				Total
	Petroleum Refineries	Iron and Steel	Direct Discharge Platers	Industries Discharging to Municipal Treatment Plants*	
0.025 -- 24-hr maximum	$5,620,000	$8,890,000	$1,320,000	$11,650,000	$27,500,000
0.025 -- monthly average	5,020,000	5,700,000	880,000	9,420,000	21,000,000
0.05 -- monthly average	2,100,000	3,450,000	680,000	1,480,000	7,700,000
0.100 -- monthly average	1,060,000	0	220,000	230,000	1,510,000
0.20 -- 24-hr maximum	1,250,000	320,000	560,000	1,100,000	3,230,000

* Excludes MSDGC's Calumet plant, which is included in the "Iron and Steel" industry category.

Table 2-6

TOTAL ANNUAL COST REQUIREMENTS FOR COMPLIANCE WITH VARIOUS STANDARDS

Effluent Standard, mg/ℓ total cyanide	Annual Cost by Industry, $				Total
	Petroleum Refineries	Iron and Steel	Direct Discharge Platers	Industries Discharging to Municipal STP's*	
0.025 -- 24-hr maximum	860,000	3,100,000	230,000	1,490,000	$5,680,000
0.025 -- monthly average	730,000	2,750,000	150,000	1,120,000	4,750,000
0.050 -- monthly average	350,000	1,540,000	120,000	240,000	2,250,000
0.100 -- monthly average	150,000	0	50,000	30,000	230,000
0.200 -- 24-hr maximum	170,000	0	100,000	210,000	480,000

* Excludes MSDGC's Calumet plant, which is included in the "Iron and Steel" industry.

The results of these analyses indicated an effluent standard between 0.075 and 0.10 mg/ℓ total cyanide based on a monthly average would be most appropriate. An effluent standard within this range represents a standard in which the marginal costs or incremental costs are equal to the marginal benefits of regulation. Although the analysis has only been conducted for the three river basins studied, an overall application of this standard would protect water quality and allow for future industrial growth on most rivers in Illinois.

If this range is considered as a state effluent standard, then the summary provided in Table 2-7 is indicative of the resulting impact. Depending upon the selection of a standard in the 0.050 to 0.10 mg/ℓ total cyanide range, the number of dischargers out of compliance will vary from 21 to 10 and the annual costs from $2,250,000 to $230,000. These values represent the estimated costs of compliance for a standard in which the marginal costs have been equilibrated with the marginal benefits of regulation, or, in other words, the maximum net benefits of regulation will be achieved.

Table 2-7

COMPARISON OF CYANIDE DISCHARGER PROBLEM FOR EXISTING AND REVISED STANDARD

	Existing Conditions	0.05 mg/ℓ CN^- Monthly Average	0.10 mg/ℓ CN^- Monthly Average
Number of Dischargers Out of Compliance			
municipalities	31	10	3
refineries	8	3	2
platers	5	5	5
steel	4	3	0
miscellaneous	26	0	0
Total Capital Cost of Compliance	$27,500,000	$7,700,000	$1,510,000
Annual Cost of Compliance	$ 5,680,000	$2,250,000	$ 230,000

Chapter 3

DELINEATION OF EXISTING CYANIDE PROBLEM

3.1 Introduction

The regulation of cyanide discharges is important in maintaining water quality and protecting aquatic life. Therefore, it is important to identify the magnitude of this problem as well as to consider future implications of the cyanide standard. Each year, the Illinois Environmental Protection Agency (IEPA) analyzes the water quality of state streams and the wastewater characteristics of dischargers to these streams. Since a consistent analytical procedure was used in compiling these data, the IEPA information was utilized to present a summary of the existing cyanide problem.

In Section 3.2, the streams in which water quality violations occurred are identified in addition to a presentation regarding cyanide levels in other important areas. This section also specifies those dischargers of cyanide by Standard Industrial Classification (SIC) code and river basin. This information adequately depicts the present impact of cyanide on Illinois waterways and its known sources. The particular cyanide levels, sources, and impact are described for four major discharger segments, the petroleum refineries, the steel industry, municipalities, and the plating industry. These four represent the groups most affected by the existing regulation and also those which have impacted water quality.

3.2 Total Cyanide Concentrations in Illinois Streams and Waterways

In 1974 and 1975, the Illinois EPA sampled all major streams for total cyanide. Their results indicated that in approximately 20 streams the 0.025 mg/ℓ total cyanide level had been exceeded on at least one occasion. The Water Quality Standards of Chapter 3 in the Illinois Pollution Control Board Rules and Regulations state that,

> "The following levels of chemical constituents shall not be exceeded: Cyanide -- 0.025 mg/ℓ"

Thus, any stream where one sample exceeded 0.025 mg/ℓ total cyanide violated the Water Quality Standards of the State.

In Table 3-1, the streams found in violation are identified by station ID, city, and percent of samples with violations. The water quality problem appeared to be regional, and Table 3-2 lists the critical areas according to county. Clearly in the Chicago metropolitan area (Planning Area 2), there appeared to be a concentration of water quality violations. The Chicago River, Calumet River, Calumet-Sag Channel, and Sanitary and Ship Canal systems contained total cyanide levels greater than 0.025 mg/ℓ. The highest total cyanide level recorded by the Illinois EPA was 0.550 mg/ℓ in Kinkaid Creek, Jackson County, followed by 0.360 mg/ℓ in the Grand Calumet at Torrence in Cook County. Such levels certainly constitute a concern for protecting aquatic biota and water quality.

3.3 Illinois Dischargers of Cyanide

There are several streams in Illinois on which a discharger of cyanide is located but no water quality problem was indicated in that segment by the Illinois EPA. These dischargers, as well as those responsible for water quality violations, will ultimately be affected by any change in the effluent standards. Since the Illinois EPA sampled all of the dischargers in the state, a summary of their data provides some perspective as to the existing cyanide levels found in treated effluents. Table 3-3 presents the establishments by Standard Industrial Classification (SIC) code who were identified as cyanide dischargers. The Appendix identifies specifically those companies used to formulate Table 3-3. Because the level of total cyanide is important in considering a rule change and economic impact, Table 3-3 also categorizes these dischargers by total cyanide concentration.

Table 3-1

WATER QUALITY STATIONS WITH VIOLATIONS OF CYANIDE STANDARD 1974-1975

IEPA Station No.	Stream	Total Number of Samples	Number of Samples Greater than 0.025 mg/ℓ	Number of Samples Greater than 0.050 mg/ℓ
AO 01	Big Creek	6	1	1
ATF 03	N. Fork Saline River	6	1	1
B 01	Wabash River	7	1	0
GBK 10	W. Branch DuPage River	7	1	1
GBKA 01	Spring Brook	5	1	0
GC 01	Jackson Creek	6	1	0
GI 04, 06	Sanitary and Ship Canal	10	2	0
GL 02	Salt Creek	6	1	0
GP 01	Wellers Ditch	5	1	1
H 01, 02, 03	Cal-Sag Channel	15	9	5
H 04, 05, 06 and	Little Calumet	16	7	4
HB 02		6	1	0
HA 01	Grand Calumet	4	1	1
HAA 02	Calumet	5	2	0
HBDD 01	State St. Ditch	2	1	1
HCA 01	S. Fork S. Branch Chicago	5	1	1
HCC 01	S. Fork N. Branch Chicago	5	1	0
JNA 01	Canteen Creek	8	1	1
NB 01	Kinkaid Creek	6	1	1
OD 04	Silver Creek	6	1	1
QH 04, QJ 08	Lake Michigan	21	3	1

SOURCE: IEPA monitoring data

Table 3-2

LOCATION OF WATER QUALITY VIOLATIONS

County	Number of Water Segments with Cyanide Violations	Planning Area
Cook	16	2
DuPage	2	2
Gallatin	1	8
Hardin	1	8
Jackson	1	8
St. Clair	2	6
Wabash	1	7
Will	1	2

Table 3-3

SUMMARY OF CYANIDE DISCHARGERS TO ILLINOIS WATERWAYS

SIC	SIC Description	Total Number of Dischargers with CN^- Present in Effluent	Number with Max. Cyanide 0.025-0.050 mg/ℓ	Number with Max. Cyanide 0.05-0.10 mg/ℓ	Number with Max. Cyanide > 0.1 mg/ℓ	Total Number Reporting Max. Cyanide > 0.025 mg/ℓ
28	Chemical	13	3	2	5	10
29	Petroleum Products	1	--	--	1	1
2911	Petroleum Refining	8	--	--	4	4
32	Stone, Glass	1	1	--	--	1
33	Steel Mfg.	10	3	4	2	9
34	Metal Treating and Fabrication	5	--	--	5	5
35	Metal Treating and Fabrication	4	1	--	--	1
4911	Electric Utilities	1	--	1	--	1
Sanitary Districts		76	14	3	14	31
Miscellaneous		7	3	1	3	7
	Total	126	25	11	34	70

Source: IEPA monitoring data

Although the petroleum and steel industry (SIC 2911 and 33, respectively) have presented a great deal of information regarding their cyanide problem, the Illinois EPA data indicates there are other dischargers who are also affected. Ten of the thirteen chemical dischargers (SIC 28) reported levels above 0.025 mg/ℓ in at least one of the samples taken by the Illinois EPA. Also, all direct dischargers within SIC 34 which includes plating operations discharged effluents with greater than 0.050 mg/ℓ total cyanide. Perhaps of greatest interest is the tabulation regarding municipal sanitary districts. Approximately 31 municipalities with cyanide levels indicated in their effluent exceeded 0.025 mg/ℓ total cyanide. This may be attributed to the plating and other metal treating discharges to the sanitary systems. Thus, the dischargers which may represent a water quality problem and could be affected by a modified regulation include chemical plants, platers, oil, steel, and at least 31 municipalities.

Either a concentration of cyanide dischargers on a waterway or a significant discharge to a small stream was presumed to affect water quality. Thus, the dischargers of cyanide were located by SIC and river system in Table 3-4. The Illinois, Des Plaines, and Fox River contain the largest number of dischargers.

Tables 3-3 and 3-4 summarized the existing water quality problems and discharger types in the state. Each discharger category is associated with cyanide waste characteristics which vary in their attributes. Therefore, the following sections present descriptions of the effluents from the major dischargers in the refining industry, steel industry, plating industry, and municipalities.

Table 3-4

LOCATION OF CYANIDE DISCHARGERS IN ILLINOIS*

River System	SIC 28	SIC 29	SIC 2911	SIC 32	SIC 33	SIC 34	SIC 35	SIC 4911	Sanitary Districts	Total
Chicago-Calumet	--	--	--	--	4	--	--	--	3	7
Des Plaines	3	1	2	--	--	--	--	--	5	11
Fox	--	--	--	--	1	1	--	--	7	9
Rock	--	--	--	--	1	--	--	--	4	5
Illinois	4	--	--	1	1	1	1	1	3	12
Mississippi	1	--	--	--	--	--	--	--	--	1
Spoon	--	--	--	--	--	--	--	--	2	2
Pecatonica	--	--	--	--	--	1	--	--	1	2
Kishwaukee	--	--	--	--	--	1	--	--	2	3
Embarras	--	--	2	--	--	--	--	--	--	2
Little Wabash	--	--	--	--	--	1	--	--	1	2
Kankakee	1	--	--	--	--	--	--	--	1	2
Lake Michigan	1	--	--	--	1	--	--	--	2	4
Horseshoe Lake	--	--	--	--	1	--	--	--	--	1
Total	10	1	4	1	9	5	1	1	31	63

* Miscellaneous category not included.

Source: IEPA monitoring data

3.4 Characteristics of Major Cyanide Discharger Categories

There are four industry segments, the petroleum refineries, steel industry, plating industry, and municipalities, which are the major contributors of cyanides. Each of these groups is differentially impacted by the current effluent standard because of their unique situation with respect to cyanide. A brief summary is provided herein for each major discharge segment which describes the existing situation within Illinois. Included is a description of the sources of cyanide, its composition, present levels in the discharge, and the compliance status. Each piece of information is important in the overall impact evaluation which is presented in Chapter 5.

3.4.1 Petroleum Refining Industry Characteristics

The petroleum refining industry in Illinois is directly affected by the existing cyanide standards of the state. All eight of the refineries that discharge directly to Illinois waterways have violated the 0.025 mg/ℓ standard during the last eighteen months. Also, the one refinery which discharges to the Metropolitan Sanitary District of Greater Chicago is concerned with the cyanide standards since Rule 703 could force MSD to impose very restrictive cyanide regulations on all sewer dischargers.

In the following sections, the origin of refinery cyanides, the quantities discharged, their effect on the receiving streams, and correlations of effluent cyanide to in-plant variables are described.

3.4.1.1 Description of Cyanide Generation

The major source of cyanide in refineries is attributed to the catalytic cracking units. Also, a small amount, typically 10% of the total cyanides, is generated in the coking units. Figure 3-1 depicts the path that the cyanide waste stream follows in a "typical" refinery.

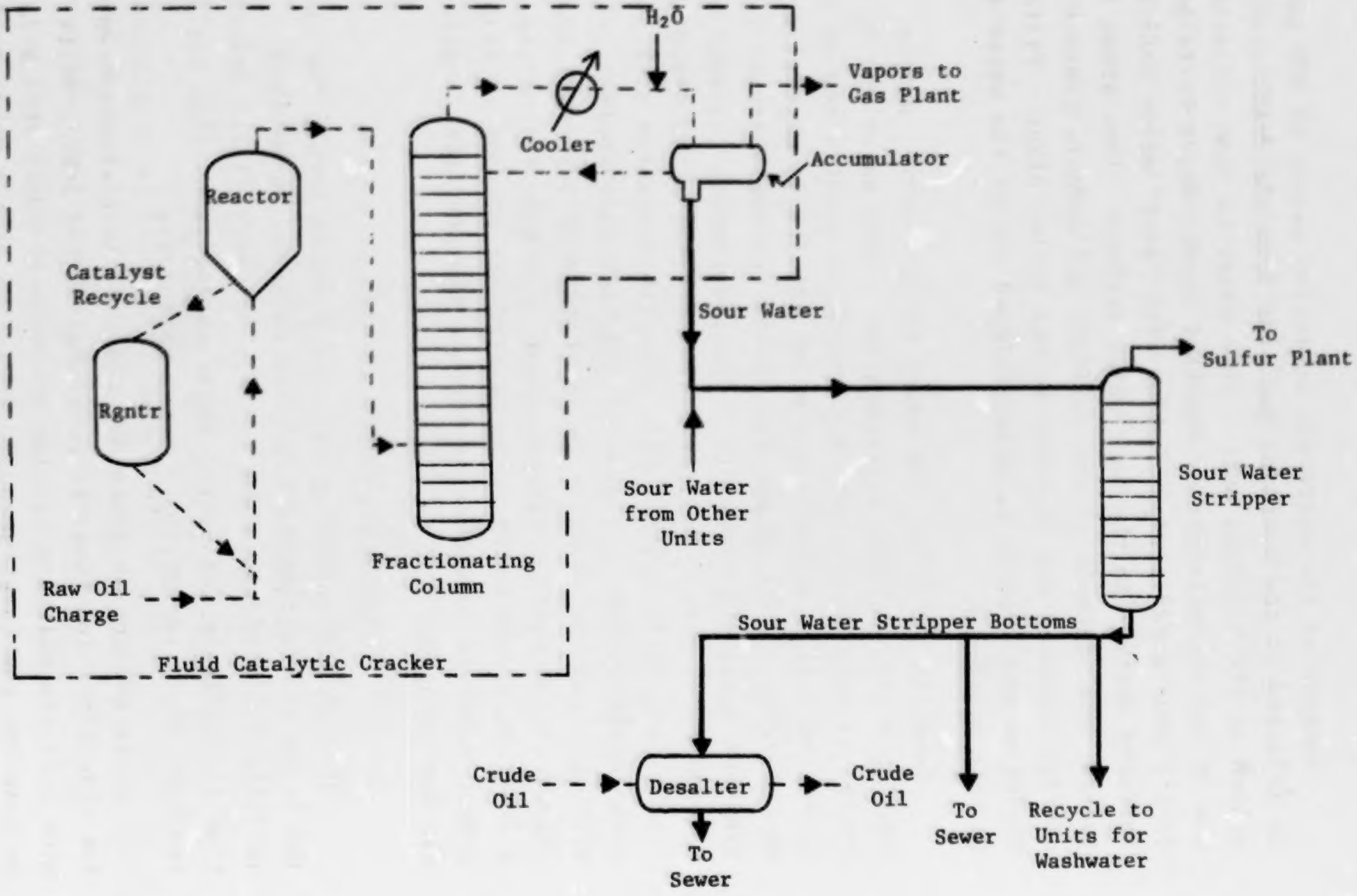

H₂O
Vapors to Gas Plant
Cooler
Accumulator
Reactor
Catalyst Recycle
Rgntr
Fractionating Column
Raw Oil Charge
Fluid Catalytic Cracker
Sour Water
To Sulfur Plant
Sour Water from Other Units
Sour Water Stripper
Sour Water Stripper Bottoms
Crude Oil
Desalter
Crude Oil
To Sewer
To Sewer
Recycle to Units for Washwater

Figure 3-1

CYANIDE GENERATION AND DISPOSAL IN REFINERY

Because of the extremely corrosive nature of HCN gas, water is injected in the overhead gas line from the fractionating column in the cracking unit. This water is then collected in one or two accumulators or knockout drums, where it is pumped to the sour water stripper along with "sour" water from other refinery units. In the sour water stripper, live steam is injected, and the bulk of the sulfides and ammonia present are carried overhead and directed to the sulfur plant. Typically, 50-70% of the cyanide is also stripped out of the water stream in this operation.

From the stripper, the water can go several places, depending upon the refinery configuration. Some water can be recycled as wash water, but this amount is constrained by the dissolved solids accumulation which results in excessive fouling and plugging. A large portion of the stripper bottoms is often used for desalting crude oil. Cyanide removal (10-80%) occurs across the desalter, but this removed cyanide may reappear in the sour water system, and, thus, this cyanide sink is of questionable value. Because of the high salt content, the effluent from the desalter is discharged to the sewer and thence to the waste treatment plant. In some refineries, a fraction of the water from the stripper bottoms is also pumped directly to the sewer because the desalter capacity has been exceeded.

3.4.1.2 Current Discharge Levels

Information regarding refinery cyanide levels for the last two years was collected, and these data are summarized in Table 3-5. Of the eight refineries, very little information is available for three, while extensive cyanide testing has been performed by three other refineries.

It is evident in Table 3-5 that the total cyanide level for all refineries exceeded 0.025 mg/ℓ on at least one occasion. If the existing cyanide effluent standard were written to consider the large standard deviation at the 0.025 mg/ℓ

Table 3-5

SUMMARY OF REFINERY CYANIDE LEVELS

Company	Crude Rate (BPSD)	Receiving Stream	Effluent Flow Rate (MGD)	Average Total CN^- Discharged (mg/ℓ)	Maximum Total CN^- Monthly Discharge (mg/ℓ)	Maximum Total CN^- Daily Discharge (mg/ℓ)	Average Total CN^- Discharged		Average % Simple CN^- of Discharge
							pounds/day	pounds/100,000 BPD Crude	
Mobil	173,000	Des Plaines R.	2.6	0.176	0.490	0.650	3.8	2.2	61
Union	154,000	Chgo. Sanitary & Ship Channel	4.2	0.079	0.296	0.730	2.8	1.8	55
Texaco(1) -- Lockport	78,000	Deep Run Creek	6.5	0.008	--	0.03	0.4	0.5	--
Texaco(2) -- Lawrenceville	92,000	Embarras R.	4.7	0.022	--	0.210	0.9	1.0	--
Marathon	102,000	Sugar Creek	2.0	0.038	0.095	0.138	0.6	0.6	--
Shell	245,000	Mississippi R.	6.8	0.045	0.136	0.213	2.6	1.1	71
American(3)	87,000	Mississippi R.	11.4	0.005	--	0.035	0.5	0.6	--
Clark	37,000	Mississippi R.	1.2	0.009	--	0.038	0.1	0.3	--

(1) Based on only 5 samples, 4 are IEPA, 1 is U.S. EPA

(2) Based on only 12 samples of IEPA

(3) Based on only 7 samples, 6 are IEPA, 1 is U.S. EPA

in the analytical procedures level, then three refineries, Clark, American, and Texaco-Lockport, would be in compliance.

Five of the refineries discharge an average of less than 1 pound per day total cyanide, while Mobil, Union, and Shell discharge an average of 3.8, 2.8, and 2.6 pounds per day total cyanide, respectively. These same three refineries have been measuring the quantity of simple cyanide (as measured by a modified Roberts-Jackson method) in their effluent. In Union's discharge, simple cyanide accounts for 55% of the total, in Mobil's 61%, and in Shell's 71%. Thus, while the refineries believe their effluent contains primarily the stable, complexed iron cyanides, their data suggests over 50% of the cyanide discharged could be in the form of a simple cyanide. The refinery data also indicates that at times the simple cyanide may account for 100% of the total cyanide found in the effluent.

The variability in the cyanide levels found in refinery effluents can be presented in a number of ways. Figures 3-2, 3-3, and 3-4 present the distribution of cyanide levels discharged by three Illinois refineries. The distribution curves appear very similar, each showing a large number of occurrences between 0.000 to 0.050 mg/ℓ and a long "tail" or skewed distribution past 0.25 mg/ℓ. All three curves indicate that any cyanide effluent standard based on a daily maximum concentration would result in violations from all three refineries, unless the standard were greater than 0.5 mg/ℓ total cyanide. These curves also suggest that a "simple" cyanide standard of 0.1 mg/ℓ based on the Roberts-Jackson method would also be violated. The simple cyanide accounts for 50-70% of the total cyanide discharged by these three refineries, and thus discharges with more than 0.15 mg/ℓ total cyanide would consistently contain between 0.05 to 0.11 mg/ℓ simple cyanide. Therefore, the refineries would have difficulty remaining in compliance with a daily maximum cyanide standard, even if the standard is based on "simple" cyanide.

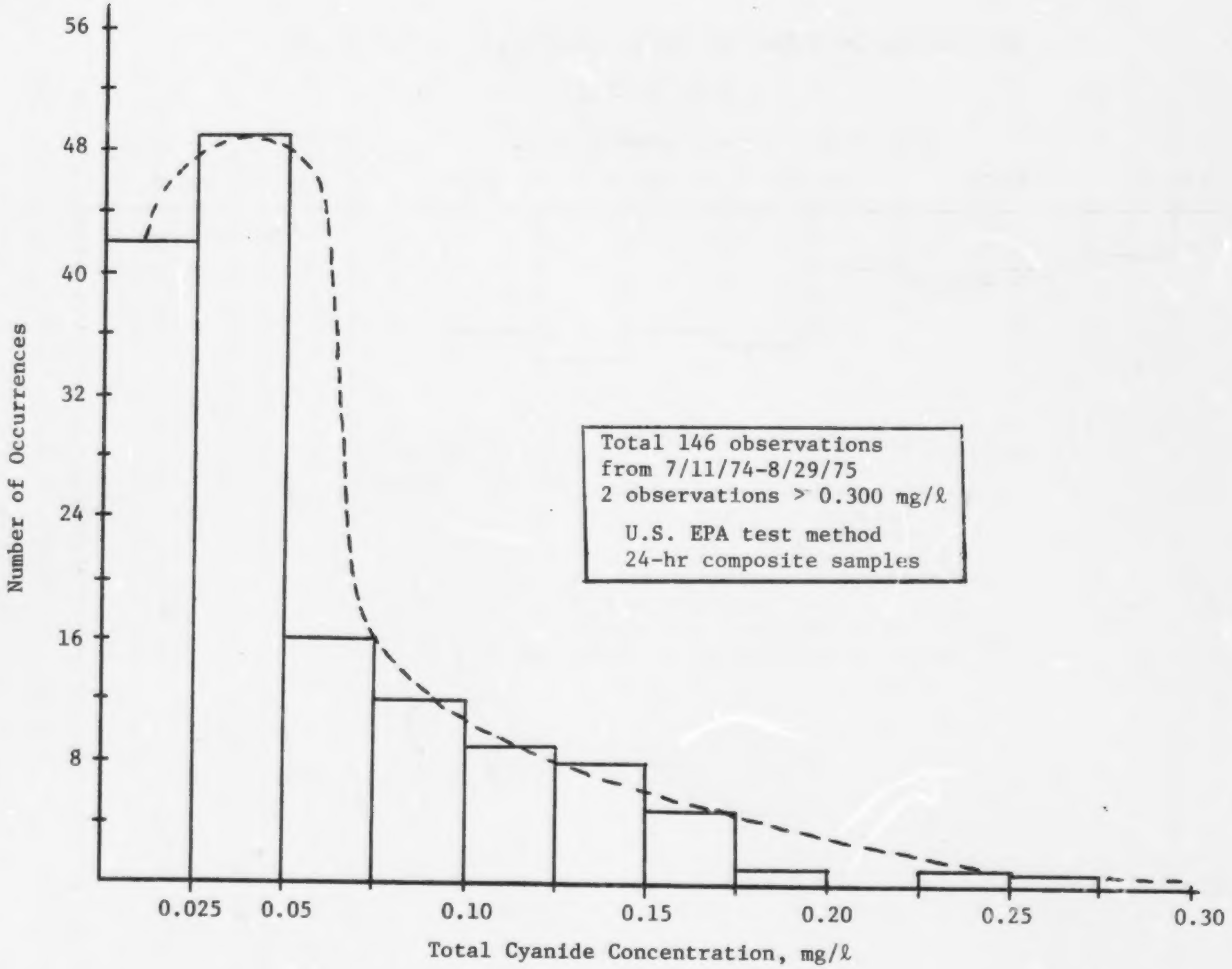


Figure 3-2

MOBIL OIL -- EFFLUENT TOTAL CYANIDE DISTRIBUTION

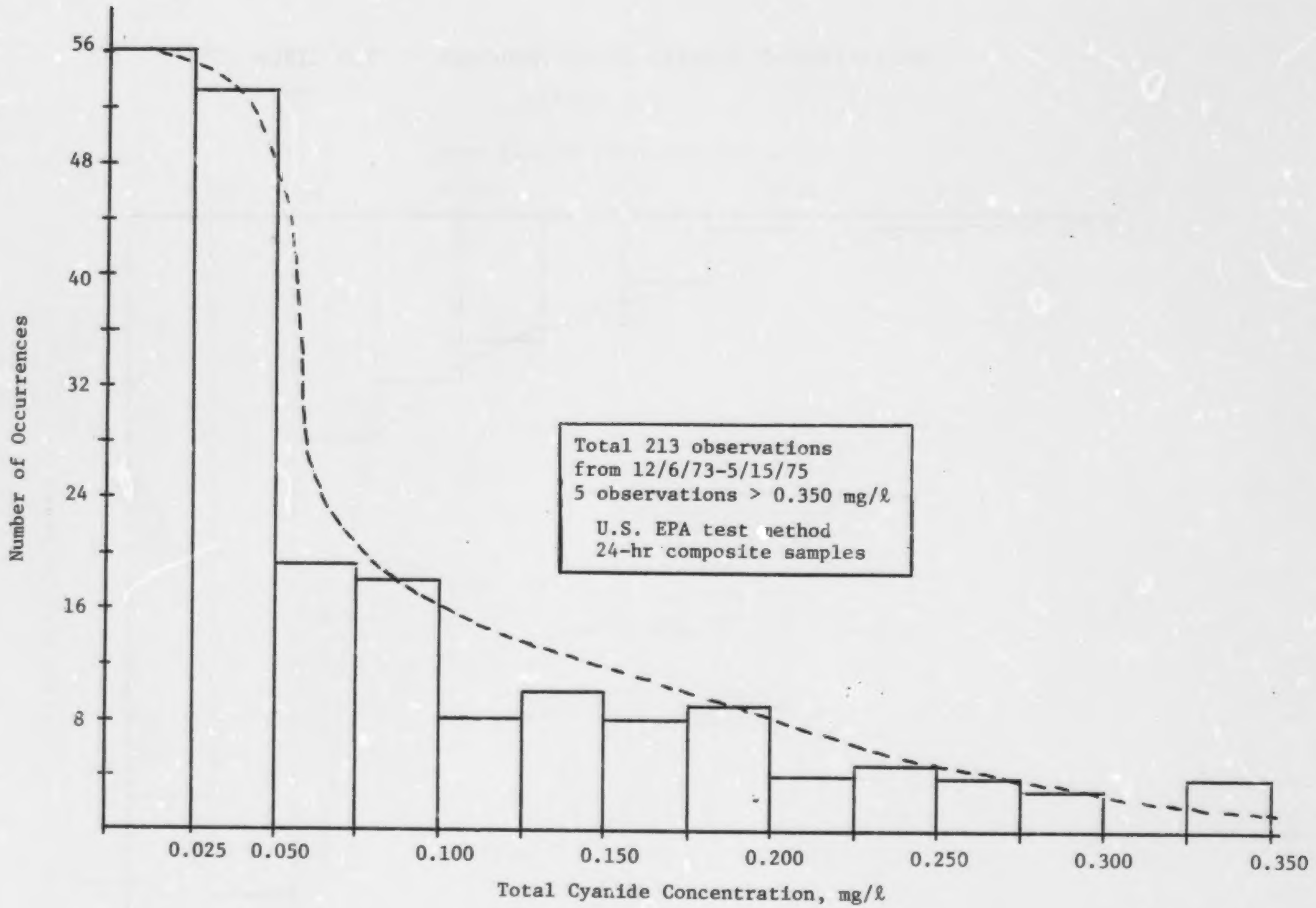
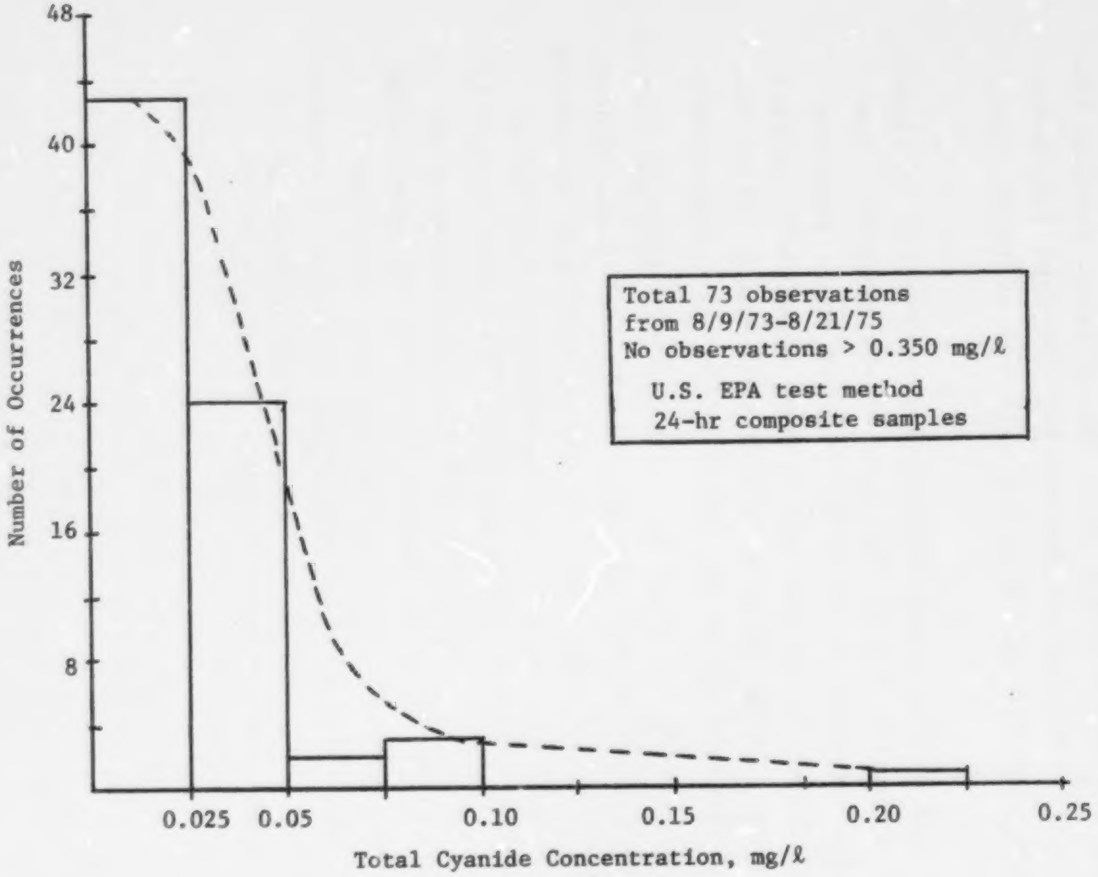


Figure 3-3

UNION OIL -- EFFLUENT TOTAL CYANIDE DISTRIBUTION



Total 73 observations
from 8/9/73-8/21/75
No observations > 0.350 mg/ℓ

U.S. EPA test method
24-hr composite samples

Figure 3-4

SHELL OIL -- EFFLUENT TOTAL CYANIDE DISTRIBUTION

A standard based on a monthly average cyanide concentration would also result in violations. Figures 3-5, 3-6, and 3-7 present the variation in the monthly average cyanide with time. Shell Oil could readily achieve a total or simple cyanide standard of 0.1 mg/ℓ, but Mobil and, to a lesser extent, Union would violate a 0.1 mg/ℓ monthly standard, total or simple based on the data of Figures 3-5 and 3-6. The effluent cyanide concentration and fluctuation in the monthly averages for these refineries are compared in Table 3-6 with the effluent flow rates.

Because the effluent concentration distribution is skewed, the standard deviation around the mean is significant. The median was also calculated for these refineries to show the difference in these two values and to more accurately reflect daily operations. Fifty percent of the time Mobil, Union Oil, and Shell were below 0.05, 0.05, and 0.025 mg/ℓ, respectively.

From Figures 3-5, 3-6, and 3-7, the monthly average cyanide concentrations appear to be lower during the last eight months. This phenomenon may be the result of two occurrences, decreased gasoline production at these refineries and closer in-house control of cyanide-bearing waste streams. The fluid catalytic cracking units (FCC) are the major gasoline-producing units in refineries. With the lower demand for gasoline, processing rates and the cracking severity in the FCC unit would be smaller, which would presumably reduce the quantity of cyanide produced. Without additional data, it is difficult to assess the relative importance of these factors.

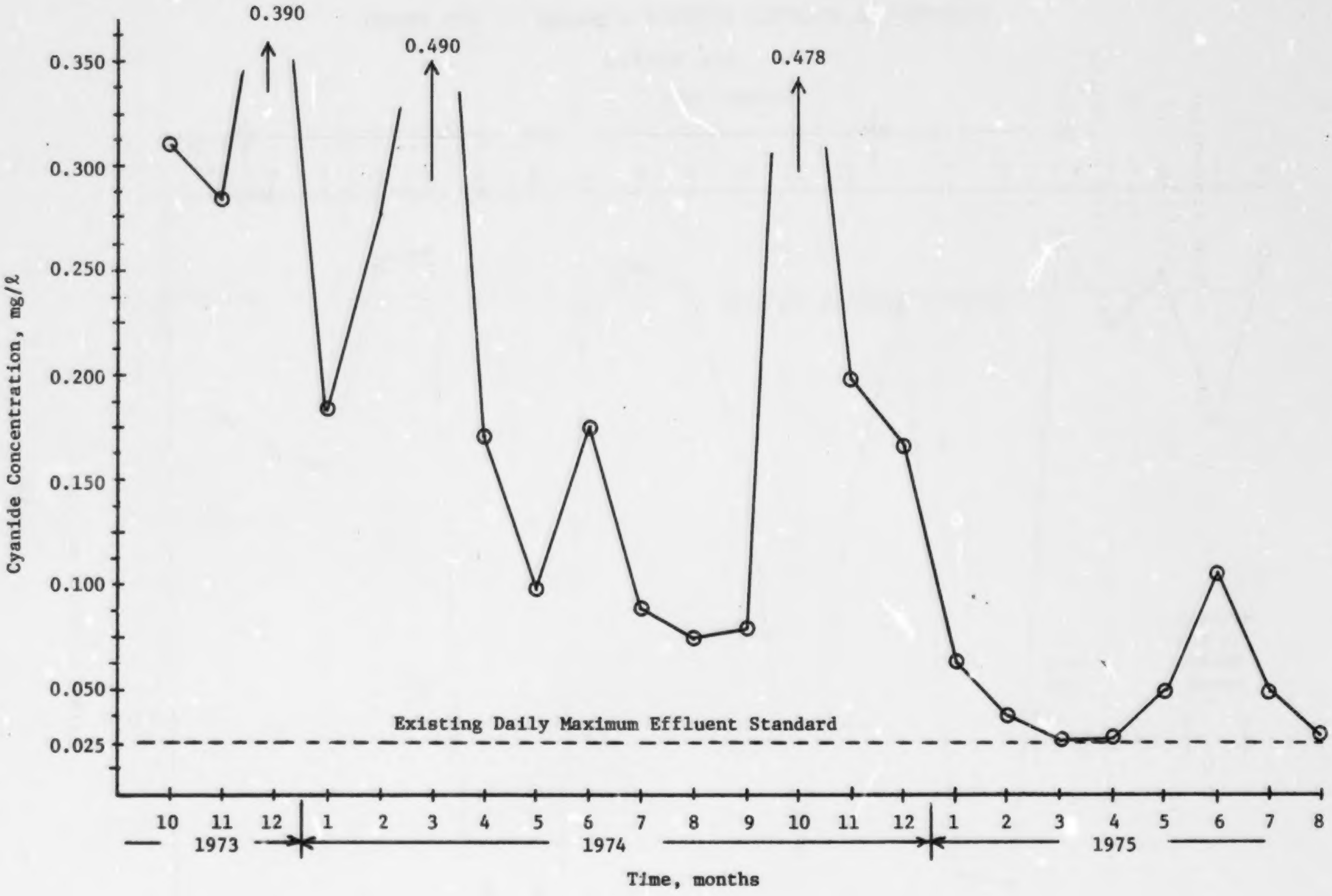


Figure 3-5

MOBIL OIL -- MONTHLY AVERAGE CYANIDE DISCHARGED

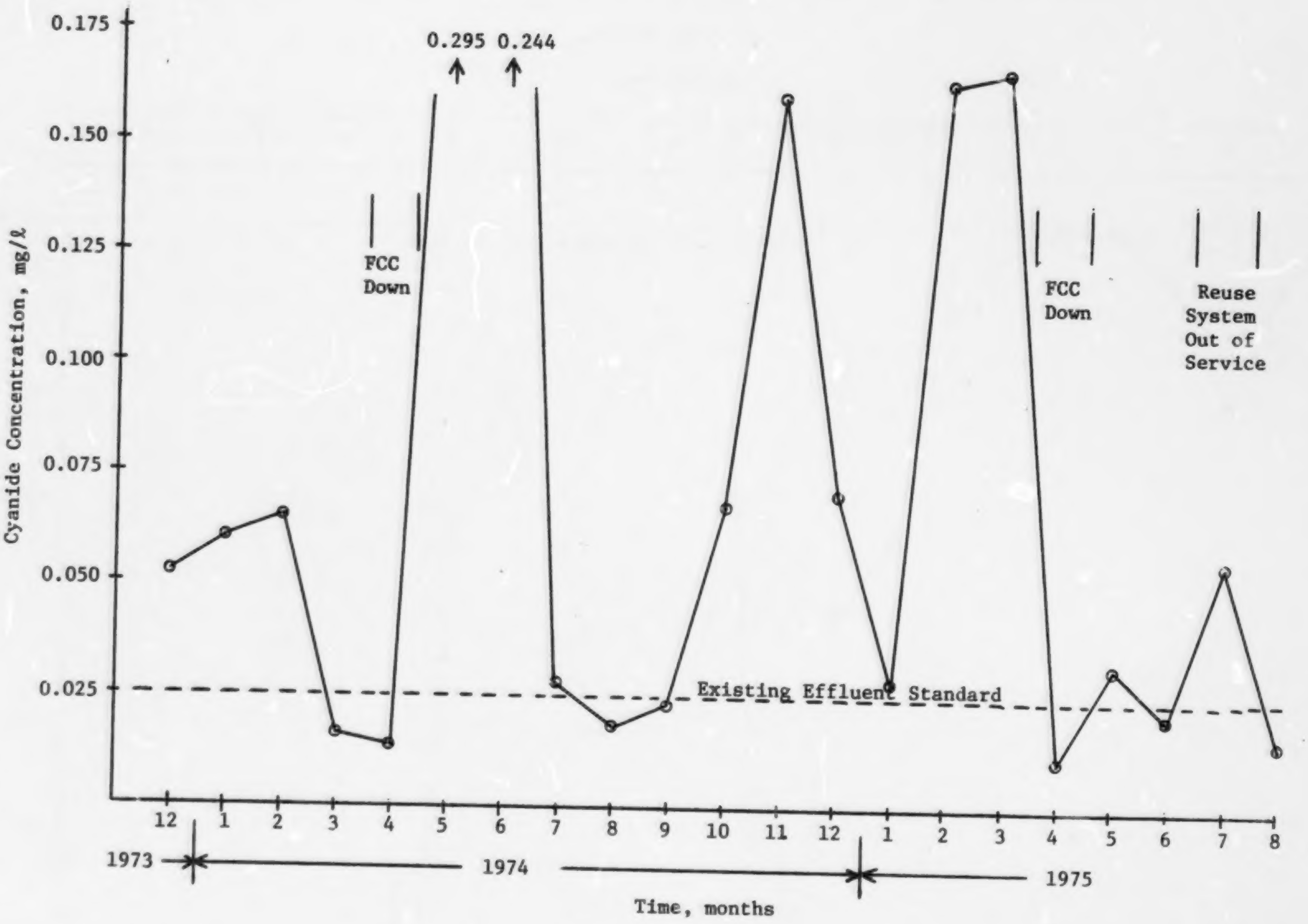


Figure 3-6

UNION OIL -- MONTHLY AVERAGE CYANIDE DISCHARGED

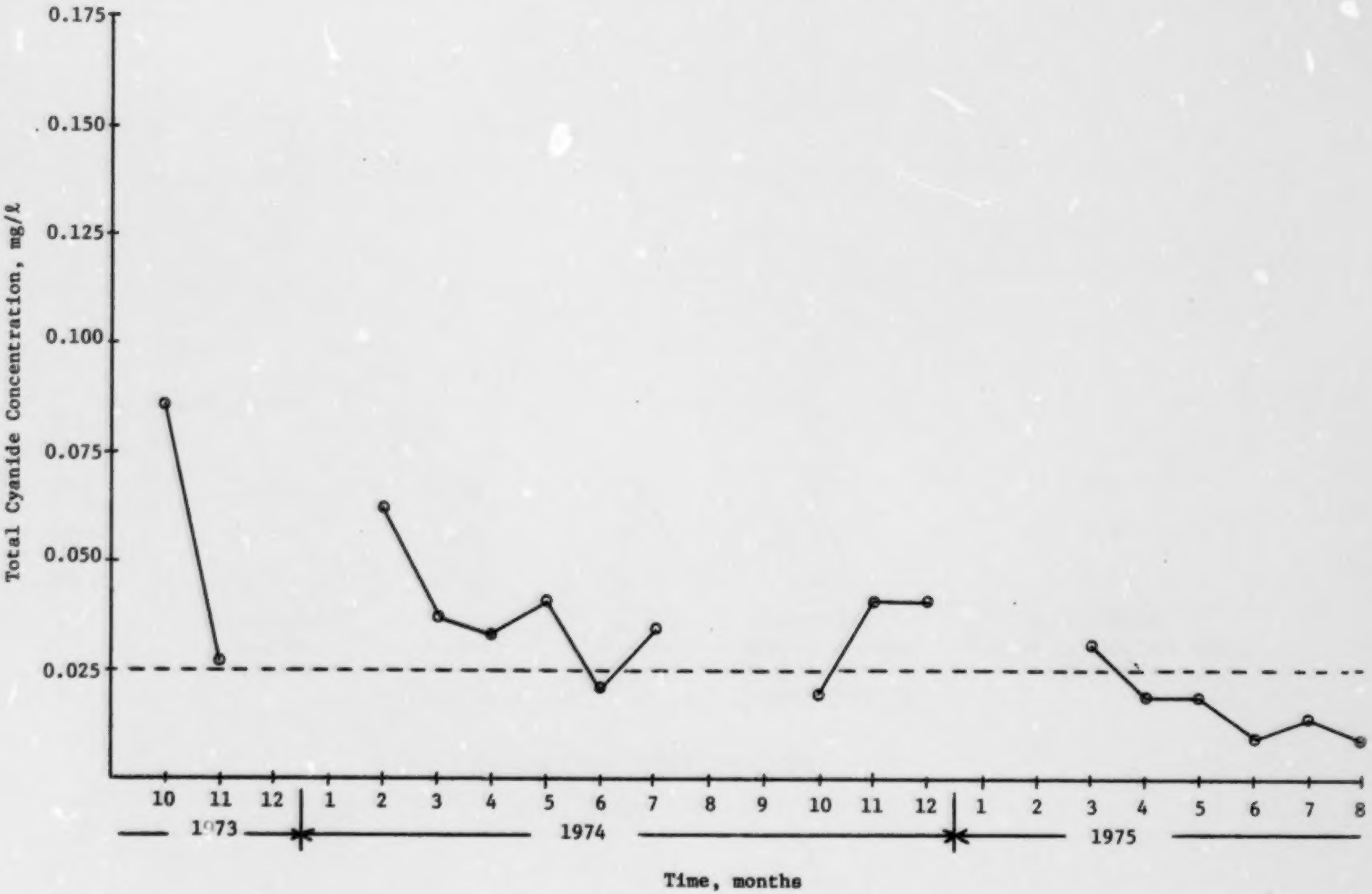


Figure 3-7

SHELL OIL -- MONTHLY AVERAGE TOTAL CYANIDE CONCENTRATION IN EFFLUENT

Table 3-6

REFINERY EFFLUENT PROFILES

	Monthly Average Concentration		Standard Deviation	Effluent Flow Rate, MGD	Effluent Flow Rate, MGD/100,000 BPD (Crude Rate)	Average pounds CN^-/100,000 BPD (Crude Rate)
Mobil	0.176	±	0.131	2.6	1.5	2.2
Union(1)	0.098	±	0.090	4.2	2.7	1.8
Shell	0.045	±	0.031	6.8	2.8	1.1

(1) 12/73 to 4/75 only

3.4.1.3 Impact on Receiving Streams

There are several sources of water quality data related to discharges from the refineries. Three of the eight refineries have monitored the cyanide levels upstream and downstream from their discharge. Additional information was obtained from U.S. EPA, IEPA, and the Metropolitan Sanitary District of Greater Chicago, who have sampled various waterways up- and downstream of refinery outfalls. Table 3-7 summarizes this water quality data for each refinery.

Mobil's 44 samples collected over the last two years averaged 0.009 mg/ℓ total cyanide both up- and downstream. The highest recorded value by Mobil was 0.030 mg/ℓ total cyanide, which is well within the standard deviation of the water quality standard, 0.025 mg/ℓ.

Fifteen samples collected upstream and downstream of Union Oil by MSD, IEPA, and the U.S. EPA showed a decrease in cyanide. The upstream values averaged 0.013 mg/ℓ, while 0.008 mg/ℓ was reported downstream. A maximum cyanide level in this stretch of the Sanitary and Ship Channel was 0.031 mg/ℓ, also well within the standard deviation of the water quality standard.

The IEPA analyzed 5 sets of samples on the Embarras River near Texaco (Lawrenceville), and reported 0.000 mg/ℓ for all up- and downstream values.

Samples collected by Shell and Clark on the Mississippi River also indicated no increase in cyanide levels after the mixing zone, and a maximum river concentration of 0.007 mg/ℓ was reported by Clark for the Mississippi River.

No water quality data was available for Deep Run Creek (Texaco, Lockport), and Sugar Creek (Marathon).

From the summary table, no water quality violations in Illinois waterways can apparently be attributed to the

Table 3-7

SUMMARY OF WATER QUALITY FOR REFINERY DISCHARGERS

Company	Receiving Stream	Total CN^- Average Discharge pounds/day	Sampling Agencies	Total Number of Samples	Average Total CN^- mg/ℓ		Maximum Total CN^- Found in River Near Discharger (mg/ℓ)
					Upstream	Downstream	
Mobil	Des Plaines R.	3.8	Mobil, U.S. EPA, & IEPA	44	0.009	0.009	0.030
Union	Chgo. Sanitary & Ship Channel	2.8	U.S. EPA, IEPA, & MSD	15	0.013	0.008	0.031
Texaco -- Lockport	Deep Run Creek	0.4	--	0	--	--	--
Texaco -- Lawrenceville	Embarras R.	0.9	IEPA	5	0.000	0.000	0.000
Marathon	Sugar Creek	0.6	--	0	--	--	--
Shell	Mississippi R.	2.6	Shell & U.S. EPA	3	0.0036	0.0034	0.0038
American	Mississippi R.	0.5	--	0	--	--	--
Clark	Mississippi R.	0.1	Clark	13	0.002	0.002	0.007

petroleum refineries. The two refineries where no water quality data is available discharge less than 1 pound per day of total cyanide.

Because of the small number of river samples collected in the vicinity of each refinery, water quality samples were probably not collected during the maximum discharge concentrations. More extensive water quality sampling is needed around each refinery discharger to verify that water quality violations do not occur during periods of maximum cyanide discharges.

3.4.1.4 Cyanide Generation and In-Plant Control

In controlling any pollutant problem, it is always advantageous to investigate the origin of the pollutant. The catalytic cracking unit is the major source of cyanide in refineries. Testimony before the Illinois Pollution Control Board[1] (PCB) for the Illinois Petroleum Council stated that:

> "...the calculated nitrogen content of crude oil and the total cyanide measured in the refinery's wastewater showed a high degree of correlation."

No data was presented to support this statement, and just which "wastewater" in the refinery was not clarified. This witness went on to say:

> "...it is apparent that cyanide generation in petroleum refineries is a very dynamic process, influenced by a variety of factors, many of which are as yet unknown."

The second statement suggests that the "high degree of correlation" was not statistically significant. To date, no information has been presented by the refineries before the PCB to explain any of the cyanide variation. If in-plant control of cyanide is to be attempted, one must understand the process and also determine what effect this type of control would have on the total refinery effluent.

The literature[2] presents a small amount of data that was recently collected at an Illinois refinery. Figure 3-8 shows the correlation obtained between the nitrogen level in the crude oil and the pounds of cyanide generated in the catalytic cracking unit. From the limited number of data points in Figure 3-8, there appears to be an excellent correlation between the two variables. Based on this study, the total pounds of cyanide generated can be predicted, but can this be correlated with the cyanide concentration of the refinery wastewater streams?

In the same Illinois refinery, the cyanide-bearing waste is pumped to the sour water stripper. Figure 3-9 shows the inlet and outlet concentration from the stripper. The outlet cyanide concentration appears to be independent of the inlet concentration. In order to determine the correlation, if any, between the cyanide levels through the treatment system, a series of regression analyses were performed. Only 15 sets of cyanide concentrations presented by Prather and Berkermeyer[2] were available for these analyses, and this limits the implications of such work.

3.4.1.4.1 Statistic Tests Utilized

The cyanide quantities at various locations in the refinery were used to determine the statistical relationships, if any, of these streams. The significance of each variable investigated was measured in two ways, the t-statistic and the correlation coefficient "R". The t-statistic can be used to show the statistical significance of variables such as x_1, x_2, and x_3 in determining Y as shown in the equation below.

$$Y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 \qquad (1)$$

The t-statistic for a specified confidence interval and degrees of freedom indicates the likelihood that α_1, α_2, α_3, the coefficients, are significantly different from zero, or, in other words, these variables are important and help determine Y's value. Using the sample data, the t-statistic for each coefficient is computed according to Equation 2.

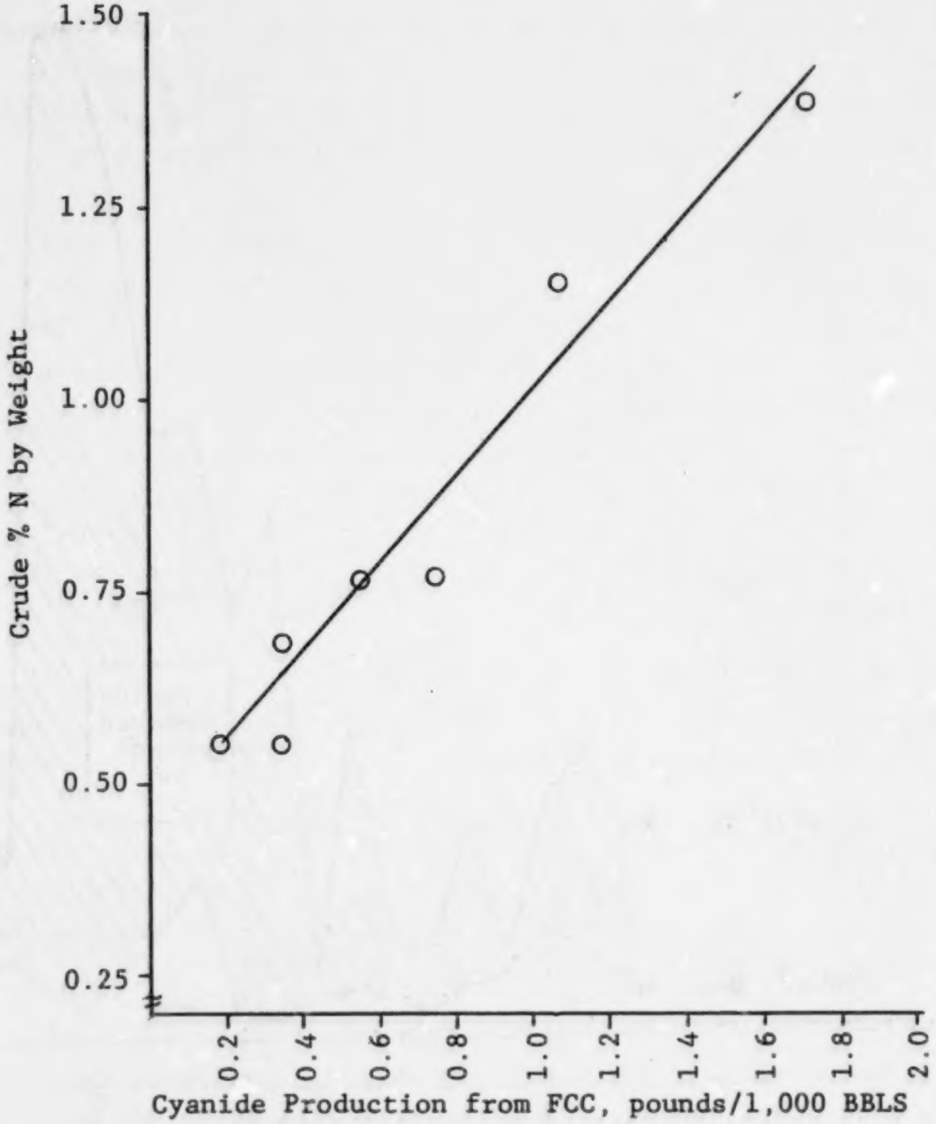


Figure 3-8

EFFECT OF NITROGEN CONTENT IN CRUDE OIL
ON CYANIDE PRODUCTION

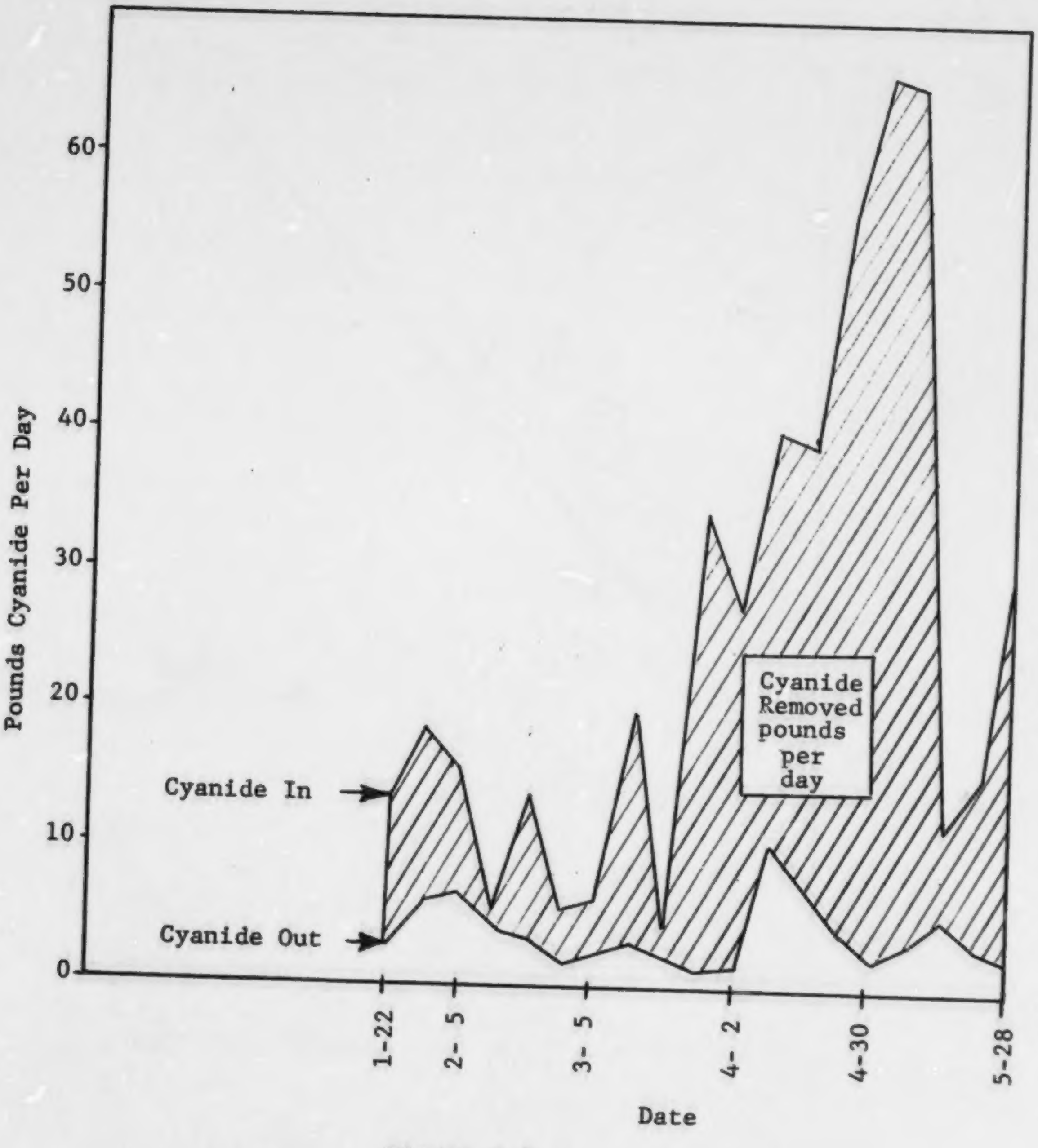


Figure 3-9

SOUR WATER STRIPPER CYANIDE REMOVAL

$$t = \frac{(\bar{\alpha} - \mu_0)}{\sigma/\sqrt{n}} \qquad (2)$$

where

α = sample value of coefficient

μ_0 = true value of coefficient

n = number of samples

σ = standard deviation

Thus, the t-statistic measures the importance of x_1, x_2, and x_3. For 14 degrees of freedom, the "t" value must exceed 2.1 in order to say, at the 5% confidence level, that "α" is different from zero, then that factor "x" does affect our dependent variable.

The R^2 value also provides a measure of the fit of sample data and the hypothesized regression line. If $R^2 = 0$, then the equation considered does not explain any of the data observed, and thus is not very useful. The maximum value for R^2 of 1.0 is only obtained when 100% of the scatter in points is explained by the hypothesized Equation 1. Thus, as R^2 approaches 1.0, the sample regression line provides a better fit or explanation of the observed data.

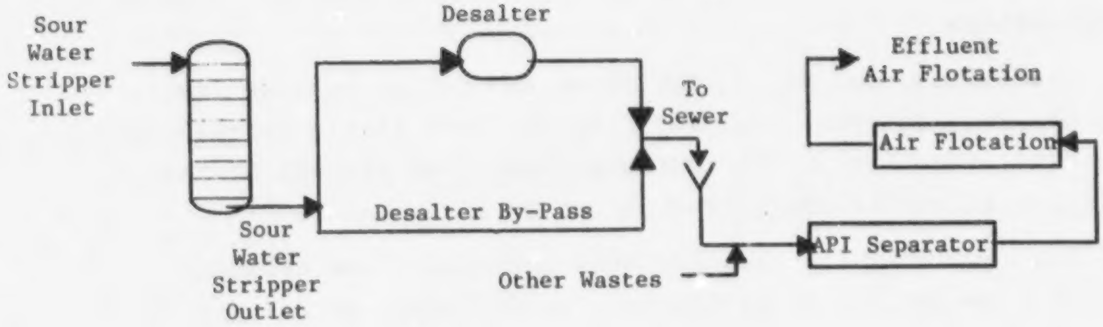
3.4.1.4.2 Results of Statistical Analysis

A series of 9 computer regression analyses were performed, the results of which are summarized in Table 3-8. The correlation of various segments of the cyanide path was examined, and the following flow diagram illustrates the course utilized.

Table 3-8

RESULTS OF STATISTICAL ANALYSIS

Computer Run	Dependent Variable	Total Cyanide Concentration, mg/ℓ						Constant	R^2 (Adjusted)
		Flow to Sour Water Stripper (gpm)	Influent Sour Water Stripper	Effluent Sour Water Stripper	Inlet to Desalter	De-salter By-Pass	Total to Sewer		
1	Effluent CN^- Concentration from Sour Water Stripper	-0.019 (-0.41)	0.030 (0.69)					3.66 (0.97)	0.000
2	Effluent CN^- Concentration from Sour Water Stripper		0.019 (0.58)					2.19 (2.17)	0.000
3	Effluent CN^- Concentration from Desalter				0.034 (1.09)			0.19 (2.40)	0.014
4	Effluent CN^- Concentration from Air Flotation Unit	0.014 (0.54)	0.006 (0.25)					-0.43 (-0.21)	0.000
5	Effluent CN^- Concentration from Air Flotation Unit	0.018 (0.95)		0.227 (1.60)				-1.2 (-0.71)	0.097
6	Effluent CN^- Concentration from Air Flotation Unit			0.228 (1.62)				0.358 (0.70)	0.103
7	Effluent CN^- Concentration from Air Flotation Unit				0.157 (0.85)	0.398 (1.40)		0.217 (0.38)	0.049
8	Effluent CN^- Concentration from Air Flotation Unit				0.402 (1.42)			0.472 (0.96)	0.069
9	Effluent CN^- Concentration from Air Flotation Unit						0.335 (1.39)	0.483 (0.98)	0.063


Sour
Water
Stripper
Inlet
Desalter
Effluent
Air Flotation
To
Sewer
Air Flotation
Desalter By-Pass
Sour
Water
Stripper
Outlet
API Separator
Other Wastes

In the first two regressions, the cyanide concentration in the sour water stripper outlet was compared to the inlet concentration and flow rate. The R^2 term in both cases (with and without the flow rate) was 0.000 and the t-statistics were less than 2.1. This indicated that none of the variation in the outlet concentration could be explained by the inlet concentration or flow rate through the stripper. This result has significant ramifications because it implies operating changes in the catalytic cracking unit to minimize cyanide production would have very little, if any, effect on the concentration of cyanide after the stripper. The t-statistic for the "constant" term is 2.17 for the second computer run and this would substantiate the hypothesis that stripping of cyanide is a concentration limiting phenomenon, or that there is a residual cyanide concentration that cannot be removed by stripping. However, this significance could also be attributed to omitted variables, which affect cyanide removal.

The data for these regression analyses were very limited, and much more data are needed before any conclusive statements can be made. These results certainly indicate, however, general relationships.

In computer run No. 3, the inlet and outlet cyanide levels from the desalter were analyzed. Again, very little correlation was found, the R^2 of 0.014 indicates that less than 2% of the variation in outlet concentration can be accounted for.

The remaining six computer runs correlated the effluent cyanide from the air flotation unit to different parameters. The best correlation was found to be with the outlet from the sour water stripper, where an R^2 of 0.103 was obtained. An R^2 of 0.103 means that nearly 90% of the variation in the air flotation effluent cyanide concentration is still unaccounted for.

The results described above indicate that cyanide removal through the refinery wastewater process is indeed very complex. Only with more data from the Illinois refineries can these preliminary findings be confirmed or refuted.

3.4.2 Steel Industry

3.4.2.1 Description of Cyanide Generation

Cyanides generated in the iron and steel making process are attributed to two sources, the blast furnace and coke plant. In the operation of a blast furnace, gases are emitted which must be scrubbed prior to burning. According to testimony by Ryckman/Edgerley/Tomlinson and Associates, Inc. (RETA)[3], this scrubber water typically contains hydrogen cyanide concentrations between 1.12 to 1.8 mg/ℓ. Figure 3-10 illustrates this basic process.

The coke oven also generates a gaseous stream, which when cooled with water becomes another source. In Figure 3-11, the gases volatilized pass through a series of coolers and,

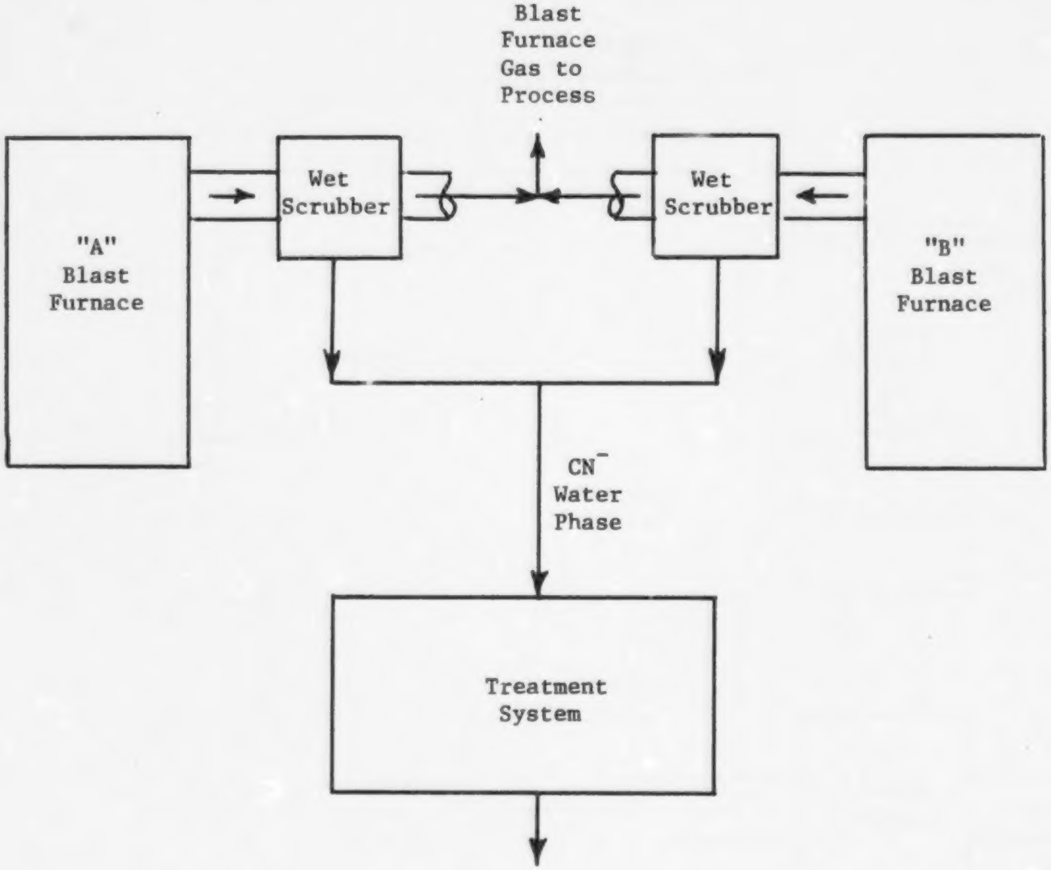

Blast
Furnace
Gas to
Process
"A"
Blast
Furnace
Wet
Scrubber
Wet
Scrubber
"B"
Blast
Furnace
CN$^-$
Water
Phase
Treatment
System

Figure 3-10

CYANIDE GENERATION IN BLAST FURNACE

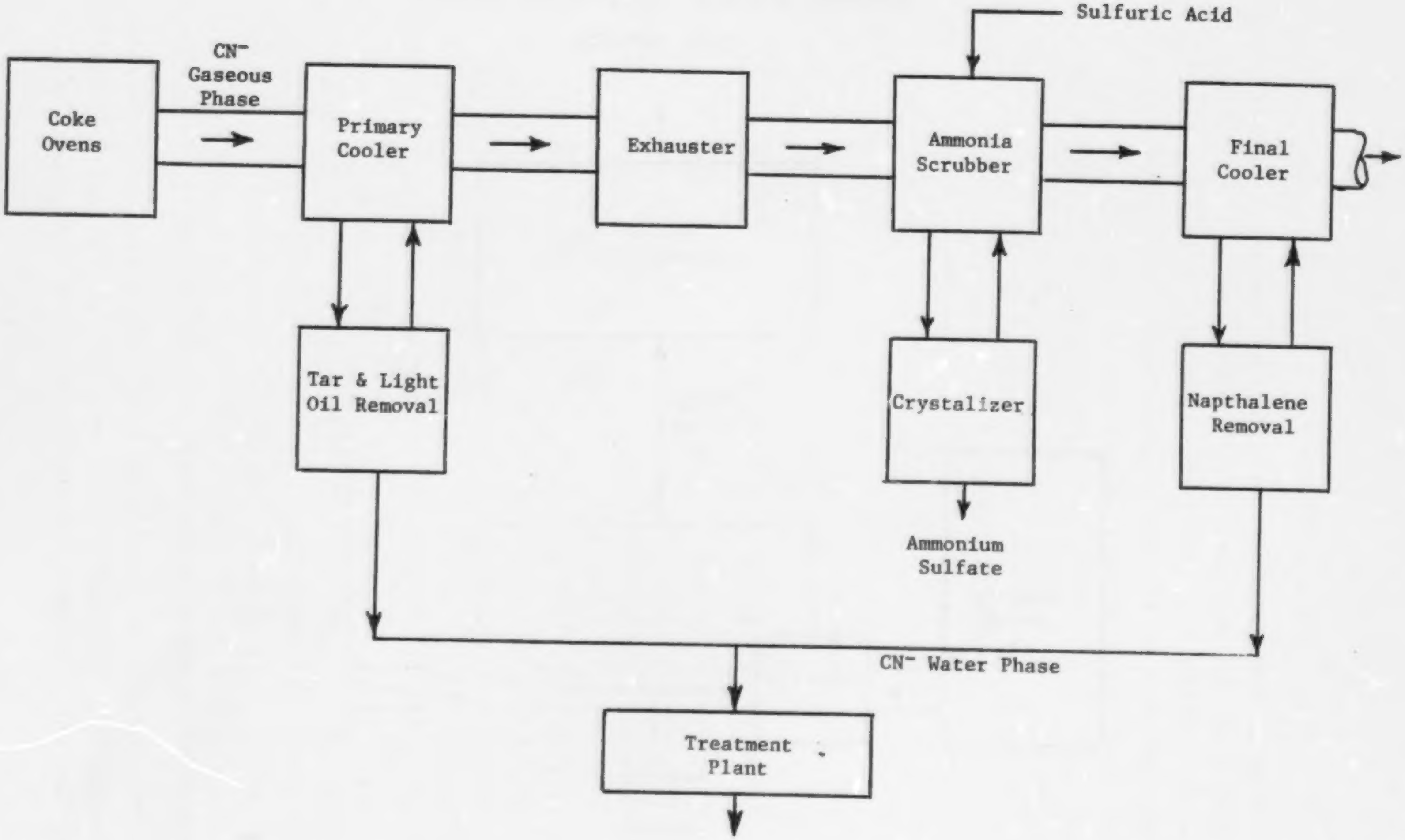

Coke Ovens
CN^- Gaseous Phase
Primary Cooler
Exhauster
Ammonia Scrubber
Sulfuric Acid
Final Cooler
Tar & Light Oil Removal
Crystalizer
Ammonium Sulfate
Napthalene Removal
CN^- Water Phase
Treatment Plant

Figure 3-11

CYANIDE GENERATION IN COKE PLANT

depending on the operation, through an ammonia scrubber. Waste streams from the ammonia still (semi-direct), interceptor sump, and final cooler all contribute cyanides, according to RETA[3]. It is important to recognize the other constituents within this waste stream because of their effect on the treatability of this waste. A typical composition[3] of a by-product coke plant is shown below.

Constituent	Concentration (mg/ℓ)
Total Cyanide	98
Phenol	300
Thiocyanate	300
Ammonia	360
Sulfide	210

3.4.2.2 Current Discharge Levels

Discharge data pertaining to operations from 1974 through 1975 was gathered from the IEPA and testimony presented at the Regulatory Hearing for Interlake, Republic Steel, and Wisconsin Steel. Table 3-9 summarizes the present discharge characteristics of these companies. After December, 1975, only Wisconsin Steel will directly discharge cyanide-bearing wastes to the Calumet River. All other blast furnace and coke plant streams from Wisconsin Steel, Republic Steel, and Interlake will be directed to MSD's Calumet plant.

The average total cyanide concentration from January, 1974 through August, 1975 for Wisconsin Steel's blast furnace discharge was 0.103 mg/ℓ, which exceeds the effluent standard of 0.025 mg/ℓ. This average represents approximately 49 pounds per day to the Calumet River. All other steel discharges will be directed to MSD's Calumet plant as of December, 1975.

The variability in discharge characteristics is related to production operations and other unknown factors. Wisconsin Steel has unsuccessfully attempted to identify the cause of

Table 3-9

SUMMARY OF STEEL INDUSTRY CYANIDE LEVELS

Company	Source of Cyanide Stream	Receiving Stream	Flow Rate (MGD)	Average Total CN^- Discharged (mg/ℓ)	Maximum Total CN^- Discharged (mg/ℓ)	Average Total CN^- pounds/day Discharged	Average % Simple (Readily Releasable) Cyanide Discharged
Wisconsin Steel (International Harvester)	Blast Furnace Coke Plant	Calumet River MSD (Calumet)	57 0.3	0.103[1] 17.09[2]	0.403 33.48	49.0 42.8	
Interlake	Blast Furnace Coke Plant	MSD (Calumet) MSD (Calumet)	0.72[3] 1.5[4]	4.2[3] 14.9[3]		25.2 186.0	38 57
Republic	Blast Furnace* Coke Plant	Calumet River MSD (Calumet)	0.54[6] 0.46[6]	0.174[5] 6.77[5]	2.87 12.0	8.6 107	-- 74
U.S. Steel (South Works)	No Sources						
Granite City Steel	Blast Furnace Coke Plant	Horseshoe Lake		0.025[7]	0.058		

* As of 12/1975 to MSD

[1] Average and maximum total cyanide from 1/1974 to 8/1975 IEPA monthly operating reports
[2] Average and maximum total cyanide from 1/1974 to 8/1975 IEPA monthly operating reports
[3] Testimony by Fred Krikau on September 26, 1975 for R-74-15, R-74-16
[4] IEPA estimate of coke oven waste flow
[5] Average and maximum total cyanide from 1/1974 to 8/1975 IEPA monthly operating reports
[6] Testimony by A. Williams on June 16, 1975, for R74-15, R74-16
[7] Average and maximum total cyanide from IEPA sampling reports

variability in cyanide concentration from the blast furnace waste stream[4]. By reviewing the 1974-1975 monthly operating reports to the IEPA, an effluent concentration distribution was composed and is shown in Figure 3-12. In all but two months, Wisconsin Steel's No. 5 outfall to the Calumet River violated the existing 0.025 mg/ℓ total cyanide. However, 11 of 19 months the average total cyanide remained below 0.05 mg/ℓ. There were four months in which treatment of cyanides was not effective as evidenced by the effluent concentrations. (These may correspond to those times Wisconsin Steel could not obtain chlorine for treatment.) Until the operating problems described by Wisconsin Steel have been resolved, there may be continuing effluent violations.

Republic Steel and Interlake, Inc. discharge blast furnace and coke plant wastes to MSD's Calumet plant, in addition to the coke plant wastes of Wisconsin Steel. These discharges must comply with 10 mg/ℓ total cyanide and 2 mg/ℓ simple cyanide. If MSD's Calumet plant violates the effluent standard, these streams may be required to meet 0.025 mg/ℓ total cyanide.

These coke plant wastes vary in concentration and quality depending upon the sources within that operation. Republic Steel indicated that the barometric condenser water, which contains primarily free cyanide, represents a significant portion of their loading. Alkaline chlorination is expected to reduce the coke plant contribution from 107 to 7 pounds per day. Interlake, Inc. also has three sources of cyanide within the coke plant, and a treatment process consisting of air stripping, pH control, and temperature control for these waters has not reduced the cyanide to present MSD compliance levels. According to Interlake, Inc., 57% of the cyanides currently discharged to the sewer are readily releasable cyanides. Wisconsin Steel does not have a barometric condenser source in the coke plant, and thus its wastes may be of a differing

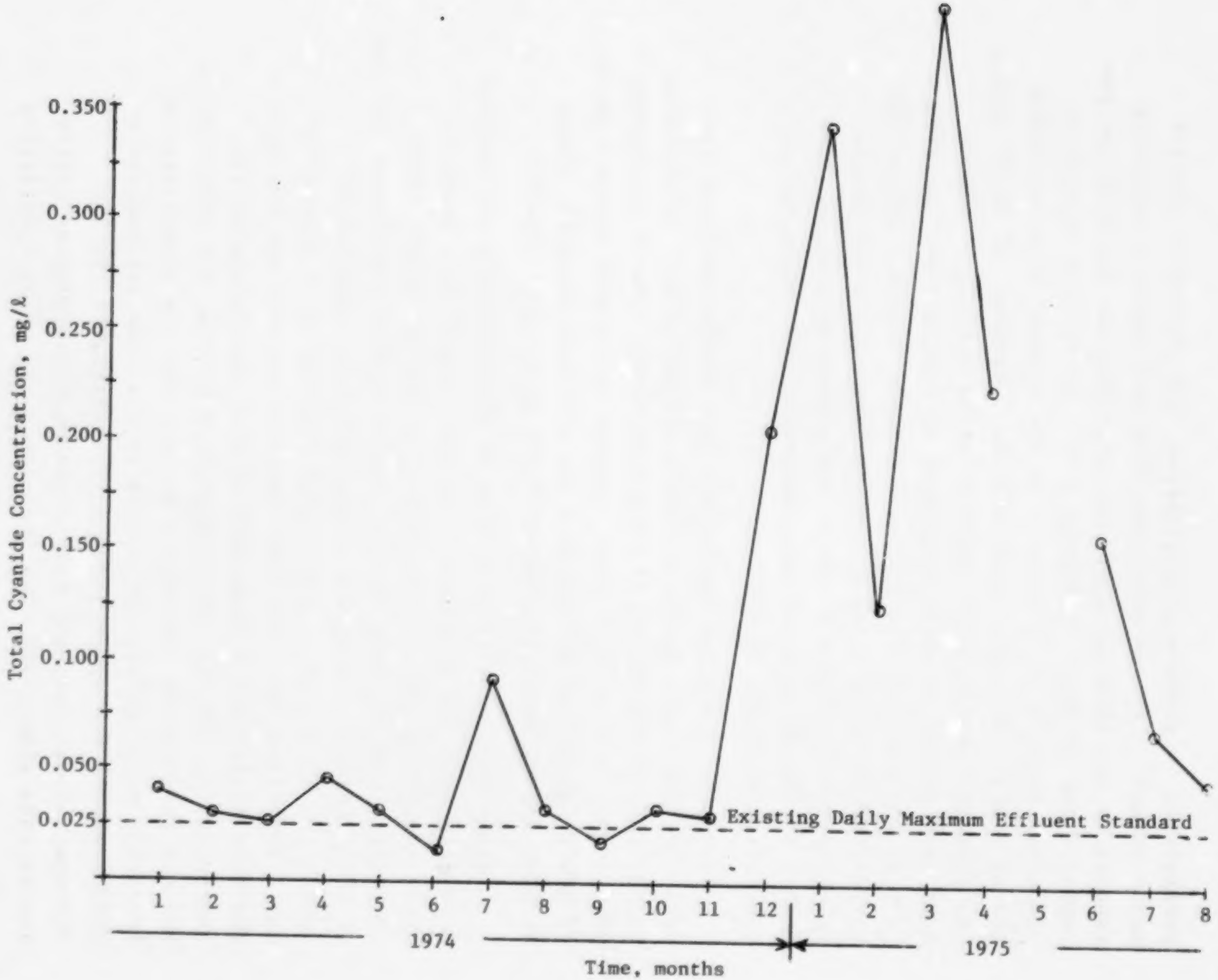

Total Cyanide Concentration, mg/ℓ
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.025
Existing Daily Maximum Effluent Standard
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
1974
1975
Time, months

Figure 3-12

composition. Laboratory treatability tests conducted by Dr. Gurnham[5] indicated that the raw coke waste contained approximately 55% free cyanide with a range of 15% to 95%.

The variability in coke plant discharges without treatment is best depicted by examining Figures 3-13 and 3-14. For Wisconsin Steel and Republic Steel, the frequency distribution of cyanide concentration is provided in these figures. Clearly, the total cyanide standard (10 mg/ℓ) of Chicago MSD is violated on several occasions. From the data presented, Wisconsin Steel was out of compliance 90% of the time and Republic Steel 20% of the time.

3.4.2.3 Impact on Receiving Streams

Of the five fully integrated steel-making facilities in the state of Illinois, only two, Wisconsin Steel and Granite City Steel, will continue to discharge directly to waters of the state. By December, 1975, Republic Steel should cease discharge of cyanide wastes to the Calumet River. The impact of these other steel companies will be discussed under municipal discharges. Wisconsin Steel and Republic Steel are located in close proximity, and both presently discharge to the Calumet River. Water quality violations were detected by IEPA in two of five samples taken on the Calumet River during 1974-1975. This problem will be reduced when Republic Steel discontinues their discharge.

Wisconsin Steel reported their monthly average river intake total cyanide concentrations from January, 1974 to August, 1975. The data is summarized in Table 3-10 for this period and indicates that water quality was violated repeatedly. The location of the intake with respect to the outfall and inadequate mixing may contribute to this effect.

Cyanide levels above 0.025 mg/ℓ were found in Granite City Steel's effluent by the IEPA. However, water quality

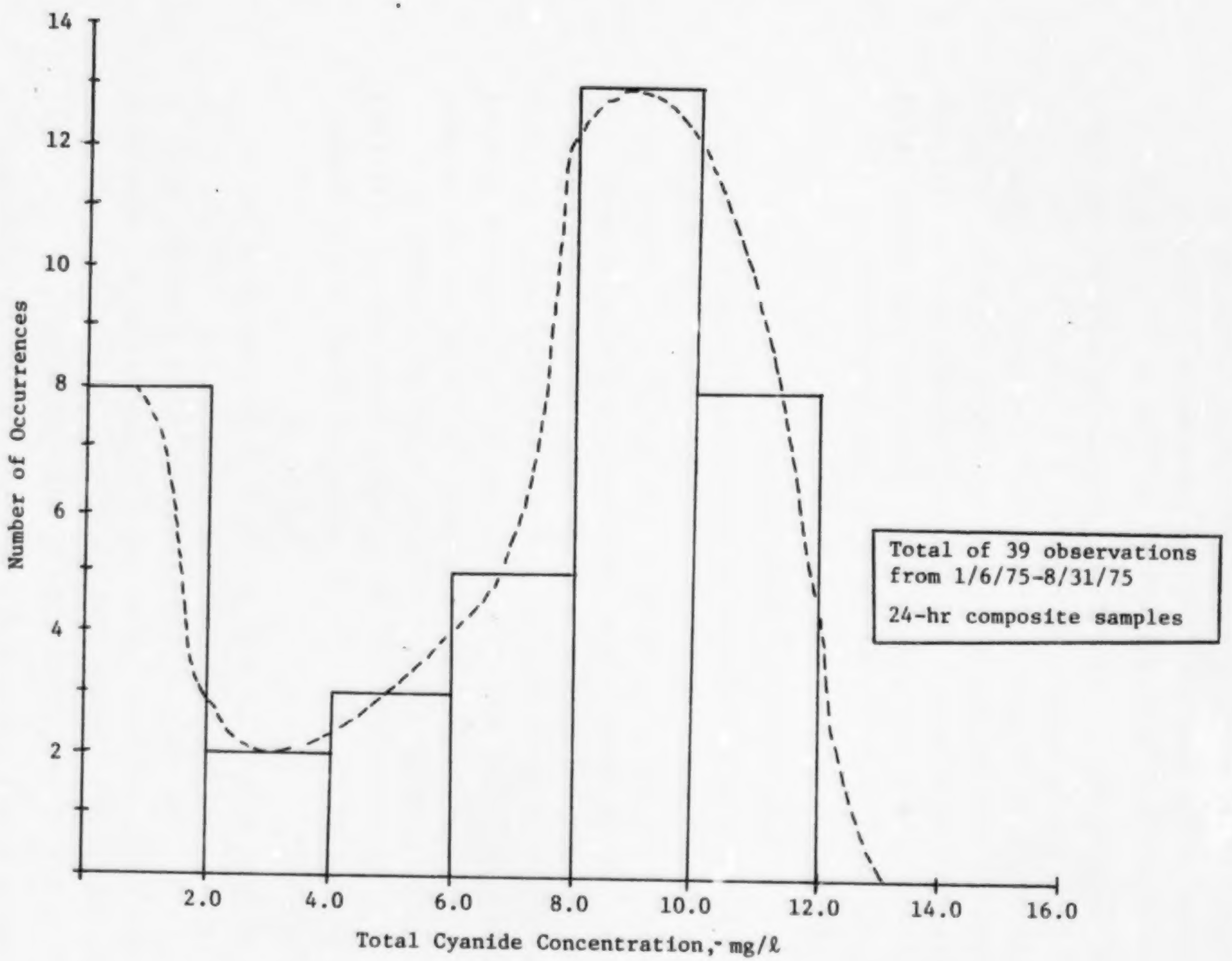
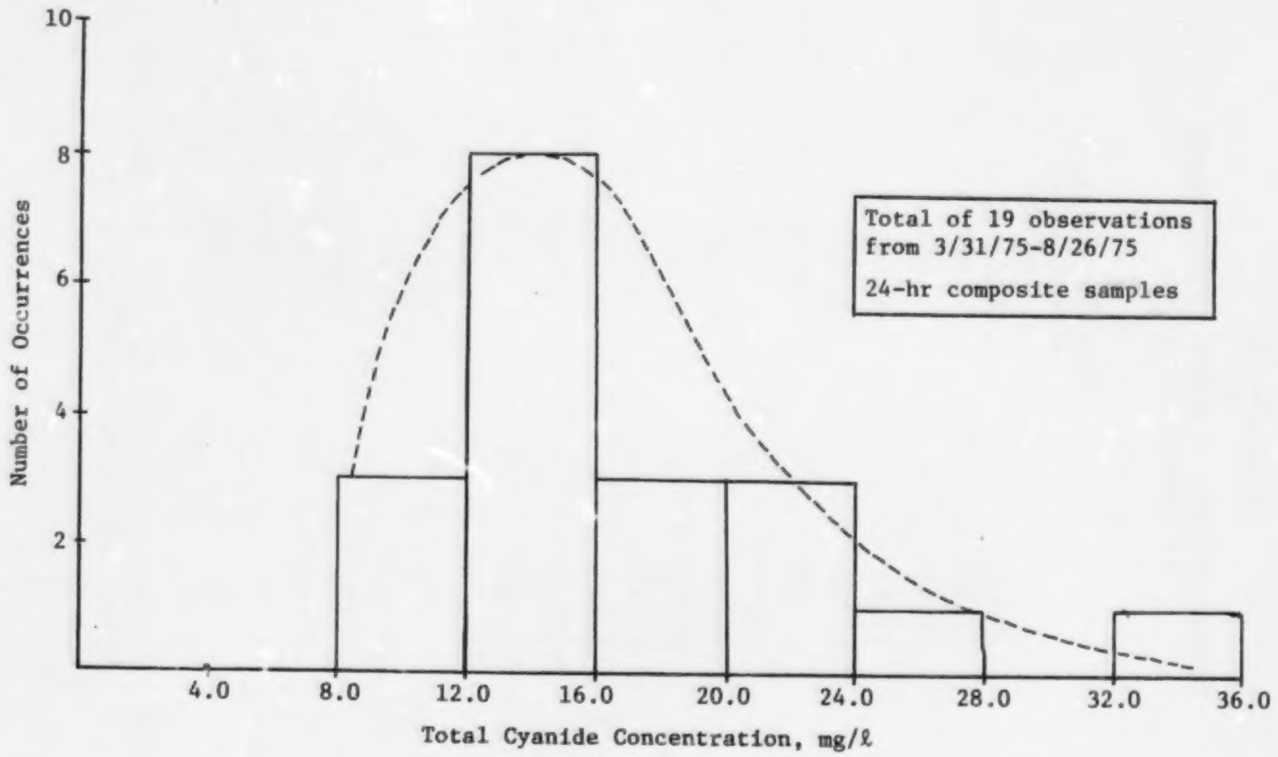


Figure 3-13

REPUBLIC STEEL -- FREQUENCY DISTRIBUTION



Total of 19 observations from 3/31/75-8/26/75

24-hr composite samples

Figure 3-14

WISCONSIN STEEL -- FREQUENCY DISTRIBUTION

Table 3-10

TOTAL CYANIDE IN RIVER INTAKE WATER OF WISCONSIN STEEL

Date	Monthly Average Concentration of Intake (mg/ℓ)
1/1974	0.022
2/1974	0.026
3/1974	0.021
4/1974	0.020
5/1974	0.018
6/1974	0.016
7/1974	0.022
8/1974	0.021
9/1974	0.013
10/1974	0.015
11/1974	0.014
12/1974	0.013
1/1975	0.122
2/1975	0.105
3/1975	0.297
4/1975	0.065
6/1975	0.134
7/1975	0.026
8/1975	0.026

Source: Monthly Operating Reports of Wisconsin Steel Submitted to IEPA samples also collected by IEPA in Horseshoe Lake were found to contain 0.000 mg/ℓ total cyanide.

3.4.2.4 Present Cyanide Treatment and Compliance

Although the present treatment efforts of the steel industry have been briefly described, a status report is presented on their discharges to MSD and waters of the state. Because all of these companies are considering additional treatment facilities for their coke wastes, the effect of such efforts must be considered. Table 3-11 illustrates the compliance status of the affected companies with respect to Rules 408 and 703. Rule 703 was construed as 2 mg/ℓ simple and 10 mg/ℓ total cyanide for dischargers to municipal treatment plants.

To impose a 0.025 mg/ℓ standard for the blast furnace and coke plant discharges to MSDGC would result in violations of all streams for all three companies.

Dr. Gurnham has performed laboratory studies for Wisconsin Steel and in his testimony[5] stated it was not possible to achieve 0.025 mg/ℓ for coke plant wastes. Other testimony offered also indicated that compliance with 0.025 mg/ℓ would be very difficult or impossible. Until the effluent standard is resolved, Wisconsin Steel and Interlake, Inc. are holding coke waste treatment systems in abeyance.

3.4.3 Municipal Dischargers of Cyanide

In assessing the magnitude of the cyanide problem, 31 municipal dischargers were identified as exceeding Rule 408 in at least one instance in 1974-1975. Thus, there are other municipalities which are affected by the proposed rule change in addition to the Metropolitan Sanitary District of Greater Chicago (MSDGC). Information was obtained regarding the operation of nine of these plants to exemplify the magnitude of this problem. These data are considered indicative of the difficulties confronting those municipalities in violation.

Table 3-11

STEEL COMPLIANCE AND TREATMENT STATUS

Company Name	Waste Source	Applicable Rule	Compliance/Treatment
Wisconsin Steel	Blast furnace	408	Out of Compliance -- Improve alkaline chlorination
	Coke oven	703	Out of Compliance -- Additional treatment required
Interlake, Inc.	Blast furnace	703	In Compliance
	Coke oven	703	Out of Compliance -- Additional treatment required
Republic Steel	Blast furnace	703*	In Compliance
	Coke oven	703	Out of Compliance -- Alkaline chlorination system being installed.

* Effective 12/1975

3.4.3.1 Sources of Cyanide

The municipal districts do not generate cyanides but rather receive industrial wastes containing such materials. There are many industrial activities occurring within cities that are responsible for such cyanide streams and although industrial pretreatment may reduce these concentrations, municipalities are not specifically designed to reduce such wastes. To illustrate the variety of operations, Table 3-12 was composed from an EPA document and conversation with municipal representatives.

Table 3-12

TYPICAL CYANIDE-GENERATING AND USING ACTIVITIES

Metal Plating
Heat Treating
Chemicals
Photography
Dyes
Tempering Steel
Process Engraving
Etching

The concentrations and form of cyanides received by these municipalities vary with the industrial activity. Regulation of the levels discharged are established by Rule 703 at 10 mg/ℓ total cyanide and 2 mg/ℓ simple cyanide. More stringent standards can be imposed at the discretion of the sanitary districts.

3.4.3.2 Current Discharge Levels

The IEPA samples all municipalities during each year for cyanide, and according to their results, 31 municipal districts exceeded 0.025 mg/ℓ. However, 14 of these were below 0.05 mg/ℓ, which could be considered in compliance adjusting for the standard deviation of the analytical procedure. Thus, there are 31 municipalities which will be affected by any change in the cyanide regulations. For nine sanitary districts, additional data was assembled, and Table 3-13 provides the characteristics of these dischargers.

Table 3-13

SUMMARY OF MUNICIPALITY CHARACTERISTICS

Name	Average Cyanide (mg/ℓ)	Maximum Cyanide (mg/ℓ)	Average Flow (MGD)	Average Cyanide (lb/day)	Maximum Cyanide (lb/day)
Aurora	0.074	0.42	24.0	14.8	84.1
Fox River Grove	0.041	0.162	0.5	0.2	0.7
East Dundee	0.012	0.04	0.45	0.04	0.15
West Dundee	0.078	0.44	0.6	0.4	2.2
Elgin	0.106	0.80	7.2	6.4	48.0
MSDGC (Calumet)	0.079	0.156	177	117	230
MSDGC (Southwest)	0.041	0.232	786	269	1520
MSDGC (Northside)	0.008	0.061	310	21	158
Rockdale	0.24	0.405	0.7	1.4	2.4

MSDGC's Calumet and West-Southwest treatment plants represent the greatest pounds per day loading discharged. However, the concentrations of the others may also present a water quality problem, depending upon the flow of the receiving stream.

The cyanide concentration frequency curves were plotted for Calumet, West-Southwest, Aurora, and Elgin. These functions for Aurora and MSDGC (West-Southwest), Figures 3-15 and 3-16, are similar to those of industry and have skewed shapes. Approximately half of the samples were below 0.05 mg/ℓ for these two plants but concentrations up to 0.20 mg/ℓ total cyanide were detected. The sample frequency curves of Elgin and MSDGC (Calumet) which are Figures 3-17 and 3-18, respectively, indicate that effluent violations predominate. The average effluent concentrations are higher for these plants that any other of the nine studied.

The MSDGC (Calumet) plant receives the coke and blast furnace discharges from the steel mills which constitutes approximately 360 pounds per day, which is a significant portion of the total plant loading which was estimated at 400 pounds per day. (Because of discrepancies in the data provided from various sources, these values represent approximations of the steel industry contribution.) Projected treatment of the coke wastes will certainly reduce the loading at MSD's Calumet plant.

MSDGC has provided data on the proportion of simple and complex cyanides (using MSDGC's test method) in their effluent. MSDGC's data, which is summarized in Table 3-14, shows that the complex cyanide represents 64-77% of the total cyanide discharged. Other municipal treatment plants with a significant number of industrial dischargers may have similar distributions, but no information is available on the effluent cyanide forms.

3.4.3.3 Impact on Receiving Streams

The 31 sanitary districts which were identified as ones exceeding the effluent standards are scattered across various

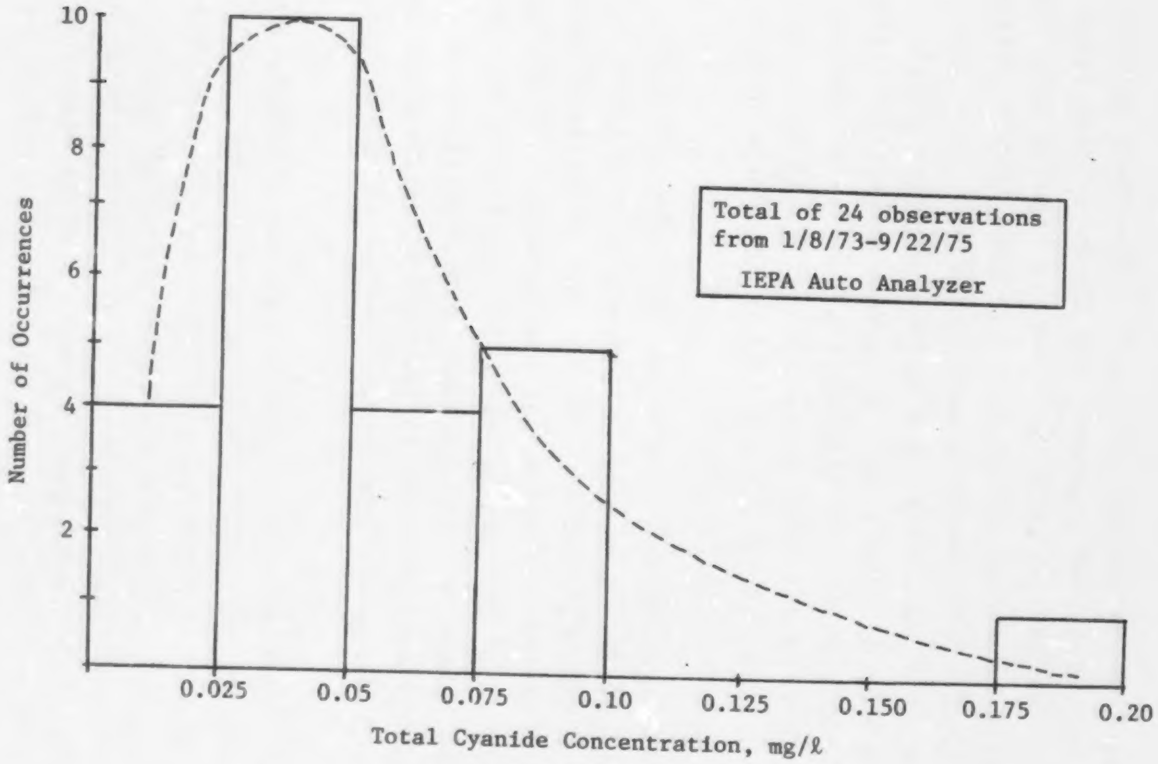


Figure 3-15

AURORA -- FREQUENCY DISTRIBUTION

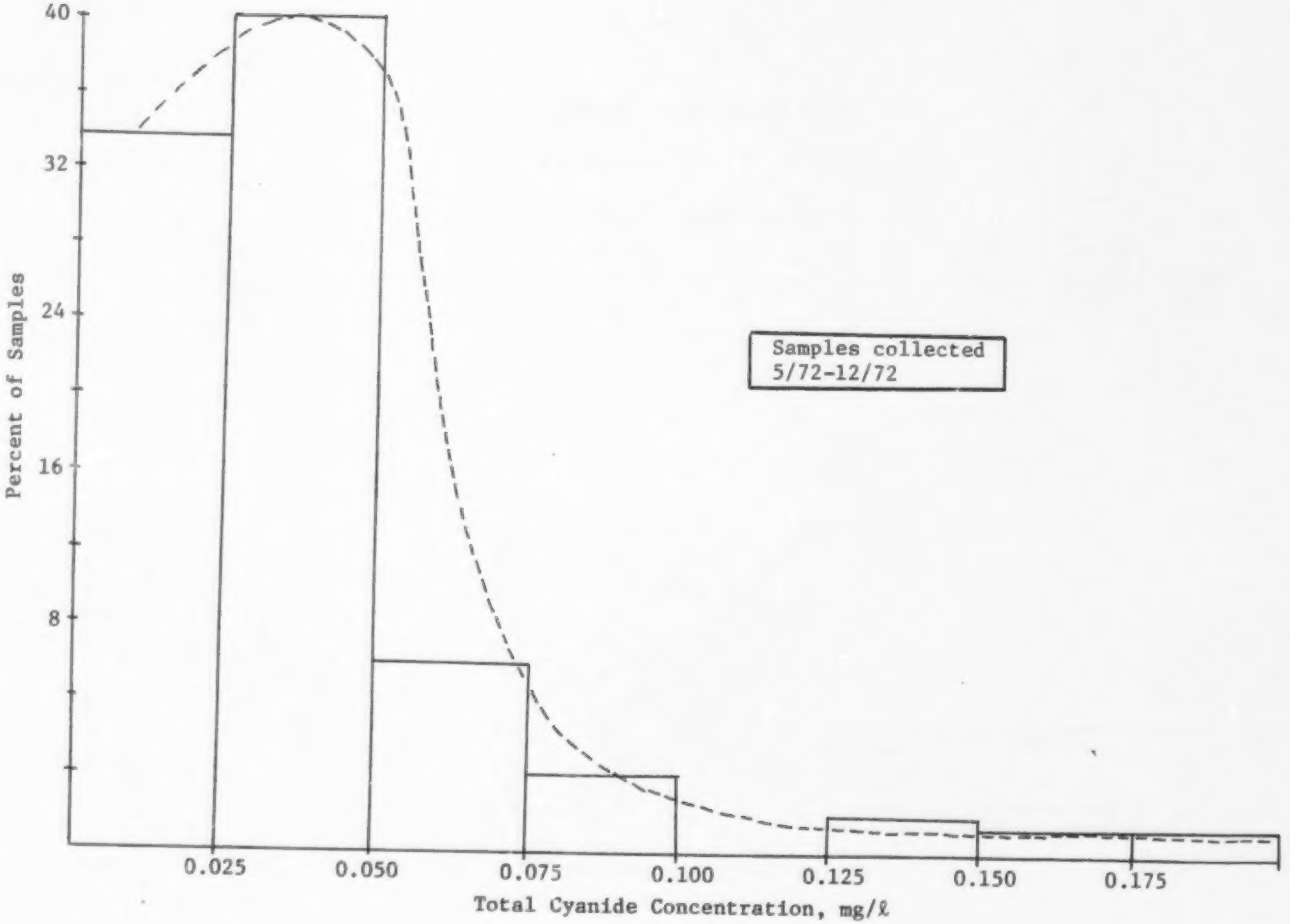


Figure 3-16

MSDGC-WSW PLANT -- FREQUENCY DISTRIBUTION

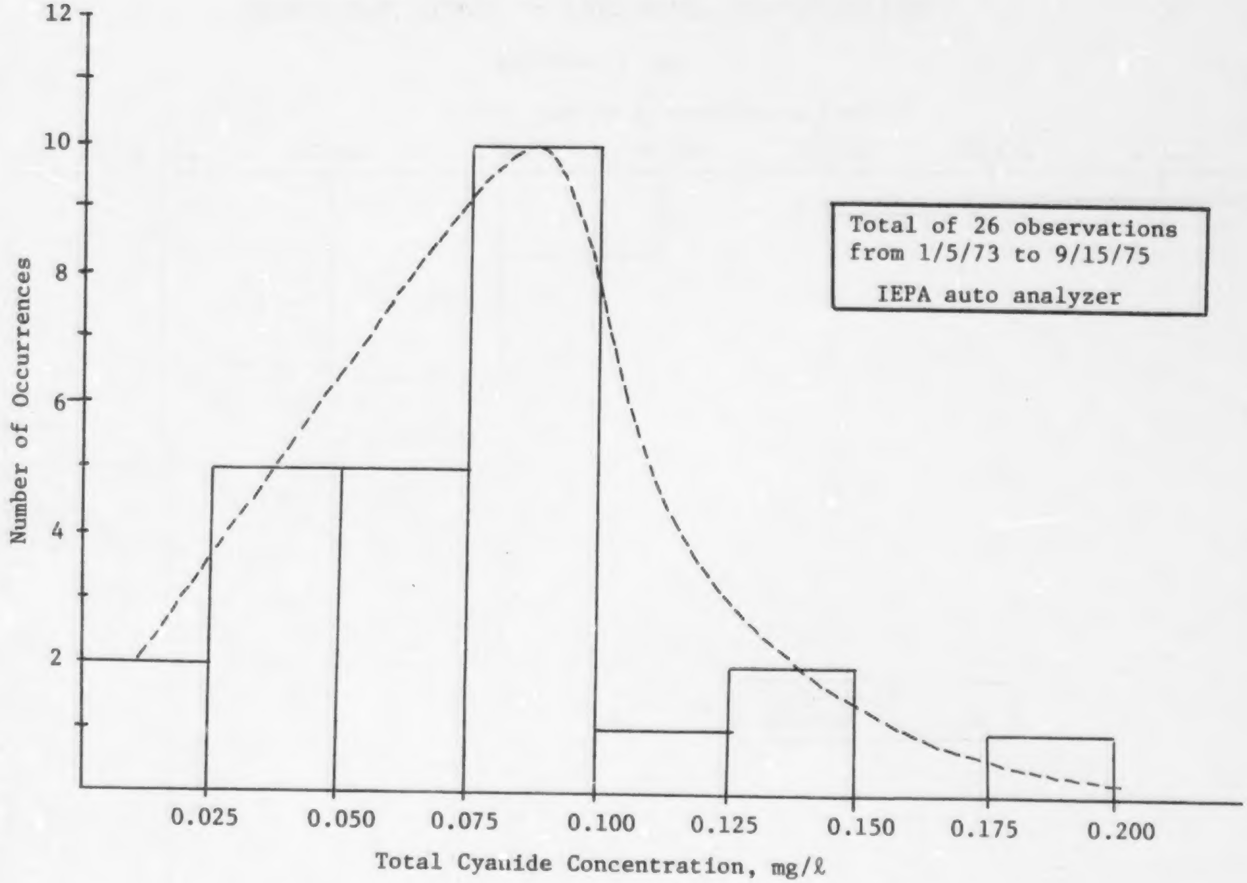


Figure 3-17

ELGIN -- FREQUENCY DISTRIBUTION

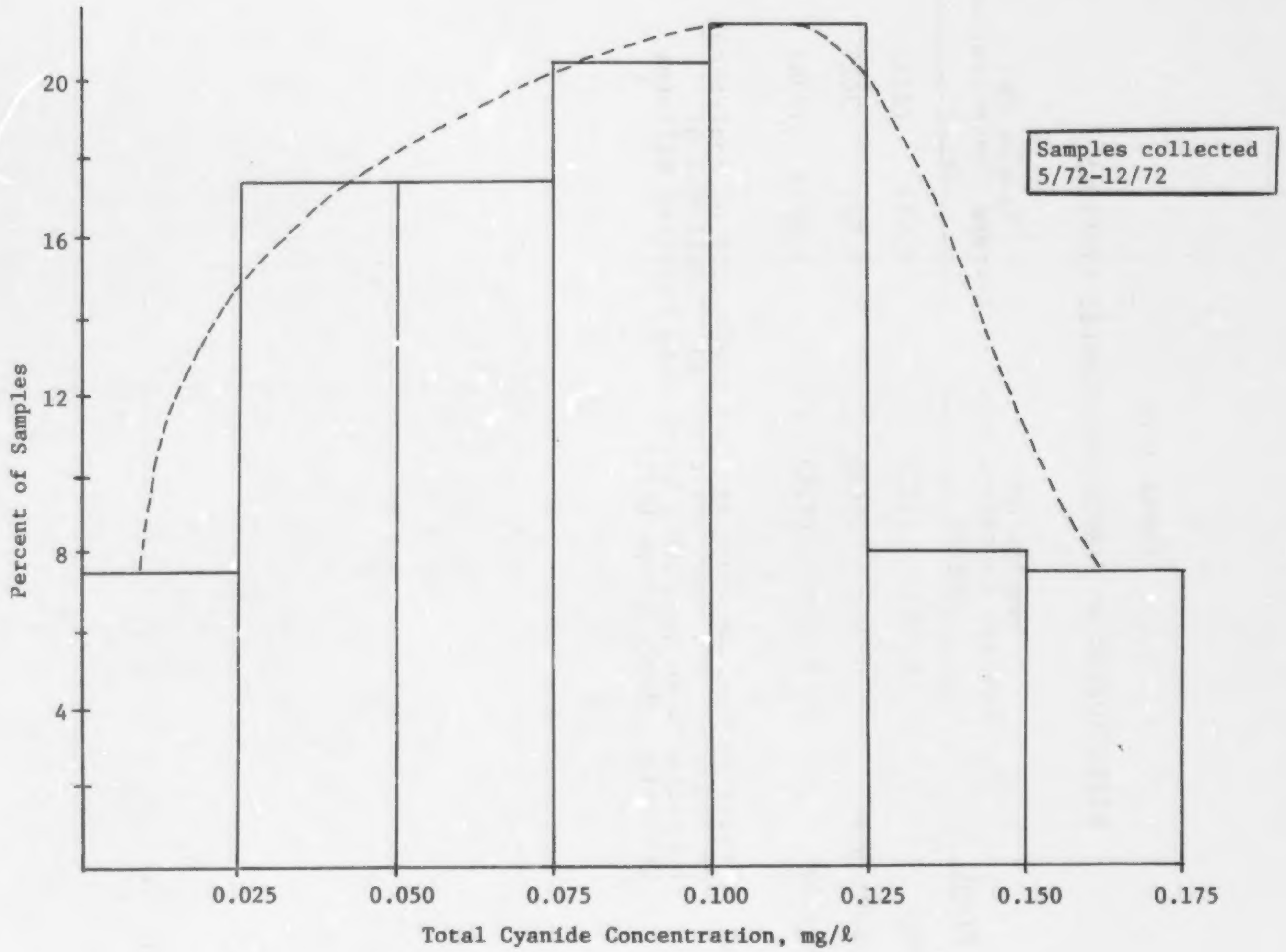


Figure 3-18

MSDGC-CALUMET PLANT -- FREQUENCY DISTRIBUTION

Table 3-14

DISTRIBUTION OF SIMPLE AND COMPLEX CYANIDES

Plant	Complex CN^- Average Concentration (mg/ℓ)		Simple CN^- Average Concentration (mg/ℓ)	
Calumet	0.083	(72%)	0.029	(27%)
West-Southwest	0.020	(64%)	0.011	(36%)
North Side	0.027	(77%)	0.0075	(23%)

Source: Report on Cyanide Studies, "An Evaluation of Analytical Methodology, Effluent Toxicity, and Compliance of Publicly Owned Treatment Works with Existing Effluent Criteria", MSDGC (June 1975).

river systems within Illinois. These plants were compared to water quality problem areas previously discussed.

Table 3-4 indicated seven plants were located on the Fox River, and this included several plants that consistently exceeded the effluent standard. However, no water quality violations have been recorded by IEPA on this waterway.

Other waterways, such as the Rock River and Little Wabash, contained cyanide dischargers but water quality data could not show any impact on these receiving streams. This phenomenon could be explained by considering the volume of water for mixing and time of travel downstream from the source.

In 1972, MSDGC performed an extensive cyanide survey on the Chicago River System. According to MSDGC data, which is tabulated in Table 3-15, there were mean total cyanide levels exceeding water quality criteria. The levels reported by MSDGC are the highest cyanide values reported in the State for any waterways.

3.4.4 Plating Industry

Plating and metal treating establishments primarily occur in industrialized areas and therefore discharge to municipal treatment plants. Only five establishments in SIC 34 were found to be discharging directly to waters of the state and to violate the 0.025 mg/ℓ total cyanide standard. Thus, the number of platers directly affected by a change in Rule 408 is small; however, those establishments associated with sanitary districts which are out of compliance represent a significant portion of the plating industry.

Table 3-15

1972 CYANIDE LEVELS DETECTED BY MSDGC

Station	Total Cyanide (mg/ℓ) Maximum	Total Cyanide (mg/ℓ) Mean
North Shore Channel		
Central Rd.	0.080	0.022
Touhy Ave.	0.096	0.039
North Branch Chicago River		
Dempster St.	0.128	0.031
Ohio St.	0.138	0.045
Calumet River		
130th St.	0.118	0.023
92nd & Ewing	0.087	0.027
Grand Calumet		
IHB R.R.	0.084	0.033
Cal-Sag Channel		
Ashland Ave.	0.068	0.030
Route 83	0.000	0.000
Des Plaines River		
Palatine Rd.	0.725	0.111
Belmont	0.070	0.027
Willow Springs	0.180	0.049

A brief description of the sources of cyanide wastes, current discharge levels, and treatment preactices is provided herein as background to their problem

3.4.4.1 Description of Cyanide Sources

In many plating operations, sodium cyanide is utilized in the bath formula because it is a good oxide solvent. In copper, cadmium, zinc, brass, and silver plating, sodium cyanide is a component of the bath. Figure 3-19 illustrates the process flow chart for four types of plating operations. After the object to be plated has received its metallic layer, there is a rinsing and drying operation.

Cyanide enters the wastewater from accidental discharges of plating solutions and contaminated rinse waters. There are several sources of accidental process discharges, such as the following:

1. process tank overflows
2. tank leakage
3. pump, hose or pipe rupture
4. drippage of workpieces during transfer between tanks
5. spills

Such occurrences would cause high concentrations (100-1,000 mg/ℓ CN^-) in the effluent until detected and corrected. Rinsing of parts is important in obtaining good quality control, and large volumes of water may be required. These rinse waters and process solution contributions are treated prior to discharge to the stream or to the municipality. However, treatment of the rinse waters, usually by alkaline chlorination, requires both pH and Cl_2 control. PH controllers are very high maintenance instruments, which in small operations such as platers, are often not properly maintained. The chlorine rate is typically set at a constant rate, and fluctuations in

Copper plating	Nickel plating	Chrome plating	Zinc plating
Electrocleaner (cathodic)	Electrocleaner (cathodic)	Electrocleaner (cathodic)	Electrocleaner (cathodic)
Running rinse →	Electrocleaner (anodic)	Running rinse →	Running rinse →
Hydrochloric acid dip (5%)	Running rinse →	Sulfuric acid dip	5% sulfuric acid dip
Running rinse →	5% sulfuric acid dip	Running rinse + spray →	Running rinse →
Copper cyanide "strike"	Running rinse →	Chrome solution	Zinc cyanide solution
Running rinse →	Bright nickel solution	Recovery rinse	Running rinse →
Running rinse →	Running rinse →	Mist spray rinse	Spray rinse →
Copper pyrophosphate solution	Soap dip	Running rinse →	Brightener still dip (HNO_3)
Running rinse →	Hot running rinse →	Hot still dip	Running rinse →
Hot rinse (slow overflow) →	Drying oven	Running rinse →	Running rinse →
Drying oven		Hot rinse (slow overflow) →	Hot water dip (slow overflow) →
		Drying oven	Drying oven

Source: Nemerow, N. L., Liquid Waste of Industry, 1971.

Figure 3-19

FLOW CHART FOR SOME COMMON PLATING BATHS cyanide levels are not compensated for with changes in the chlorine rate. Thus, if some of the parts being plated "slop" over cyanide solution, the rinse cyanide concentration will increase and the alkaline chlorination unit will not compensate for the higher inlet cyanide concentration, resulting in excessive cyanide levels in the effluent.

3.4.4.2 Present Discharge Levels

Currently, there are five direct discharge plating operations which are not in compliance with Rule 408, according to IEPA data. Spartan Manufacturing, American Nickeloid, Aubrey Manufacturing, Modern Plating, and Woodstock Die Casting all exceeded 0.025 mg/ℓ total cyanide during 1974-1975. Samples taken by IEPA for these dischargers are summarized in Table 3-16. The high average values indicate that these establishments are out of compliance and should require additional control or treatment.

Only total cyanide levels were analyzed and reported. Therefore, one cannot determine the amount of free or simple cyanide present in their effluent.

3.4.4.3 Impact on Receiving Streams

The impact on the receiving streams is summarized in Table 3-17. Very little data are available on the water quality near plating dischargers; however, water quality violations can be expected to result from cyanide discharged from Woodstock Die Casting and Spartan Manufacturing, although no actual data are available. Modern Plating discharges an average of 5.9 pounds per day total cyanide, which is more than any petroleum refinery in Illinois. At the 10-year, 7-day low flow, the cyanide level in the Pecatonica River would be increased by 0.009 mg/ℓ from Modern Plating's average discharge.

Table 3-16

DISCHARGE CHARACTERISTICS

Company	Number of Samples	Total Cyanide	
		Average Conc., mg/ℓ	Maximum Conc., mg/ℓ
Spartan Manufacturing	2	0.194	0.388
American Nickeloid	3	0.103	0.220
Aubrey Manufacturing	13	0.208	0.690
Modern Plating	9	1.173	3.600
Woodstock Die Casting	8	0.082	0.470

Table 3-17

SUMMARY OF WATER QUALITY FOR PLATING DISCHARGERS

Company	Receiving Stream	Average Discharge Total Cyanide pounds/day	Water Quality
Spartan Mfg.	Seminary Creek	--	No data available; however, this is an intermittant stream, probable water quality violations
American Nickeloid	Illinois R.	0.1	IEPA data shows 0.000 mg/ℓ upstream 0.000 mg/ℓ downstream
Aubrey Mfg.	Kishwaukee R.	--	No data available
Modern Plating	Pecatonica R.	5.9	IEPA data shows 0.000 mg/ℓ upstream 0.000 mg/ℓ downstream*
Woodstock Die Casting	Creek that feeds Wonder Lake	0.5	No data available, probable violations. The City of Woodstock also discharges cyanide. These two sources are the primary dry weather flow in creek.

* Theoretical impact on receiving stream at 10-year, 7-day low flow is 0.009 mg/ℓ total cyanide.

4. FATE OF CYANIDE IN RECEIVING STREAMS

In order to properly assess the impact of an effluent regulation, one must determine the fate of the regulated pollutant once it enters the receiving stream. Many pollutants, such as heavy metals, are treated as "conservative" pollutants, while others, such as biochemical oxygen demand (BOD), and ammonia, are considered degradable, or "non-conservative". The assimilative capacity of a receiving stream is greater for a non-conservative pollutant as opposed to a conservative pollutant of equal toxicity because of the decay factor for non-conservative pollutants.

In the following sections, a summary of possible cyanide removal mechanisms in receiving streams is discussed, as well as four river basins where the decay rate was calculated.

4.1 Aspects of Cyanide Degradation

The biological activity in rivers is similar to that of treatment systems, such as activated sludge, in that the bacteria become acclimated and will degrade the organics present but at a slower rate. Thus, if cyanides are removed by wastewater treatment plants, one would perhaps expect a similar phenomenon to occur in the receiving stream. James Irvin[6], reported cyanide removals in biological treatment plants of over 99% for potassium cyanide and the complexes of zinc and cadmium, while a 75% reduction in copper and nickel cyanides was also related. Iron cyanide removals were obtained, but removals varied from 20 to 70%.

Another report substantiating this cyanide reduction was that of the Metropolitan Sanitary District of Greater Chicago (MSDGC), who reported[7] cyanide removals across their treatment plants. Their data is shown in Table 4-1.

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TABLE 4-1

CYANIDE REMOVALS ACROSS MSD TREATMENT PLANTS

TREATMENT PLANT	TOTAL CYANIDE* AVG. CONCENTRATION (mg/ℓ) RAW	FINAL	% REMOVAL
Calumet	0.175	0.079	55
West-Southwest	0.220	0.041	81
North Side	0.089	0.008	91
Hanover Park	0.003	0.005	--
Lemont	0.022	0.016	27
Streamwood	0.007	0.016	--

*Total cyanide measured by Standard Methods.

According to Table 4-1, there is a definite removal across the treatment plants with high influent cyanide concentrations. Calumet, West-Southwest, and North Side, who reported the highest cyanide levels, experienced a 55%, 81%, and 91% reduction in total cyanide concentration. No significant reduction in total cyanide occurred, however, for those with less than 0.025 mg/ℓ total cyanide in their influent.

Indeed, if cyanide is degraded within biological systems, then the mechanism by which cyanide is removed is also of concern. If adsorption of cyanide onto particulates is the primary removal mechanism, cyanide could possibly concentrate in the river sediment which might result in an increasing accumulation in the food chain. Raef, et al.[8], investigated the removal of potassium cyanide in an activated sludge system, and found the following:

a) Major removal of cyanide occurs via reactions with aldoses (such as glucose) and cyanide at pH's above 8.

b) Cyanide stripping and cyanide metabolism are important removal mechanisms.

c) Adsorption of cyanide on biological floc occurs, but to a lesser extent than a) and b).

One may infer from these results that any cyanide removal occurring in a river would be attributed primarily to reaction, stripping, or biodegradation mechanisms as opposed to adsorption onto particles which settle and accumulate on the river bottom.

Based on the above discussion, cyanide appears to be a degradable substance. If this is the case, then the rate of cyanide disappearance becomes important. Utilizing the data from four river basin studies, cyanide mass balances were calculated and are summarized below.

4.2 Cyanide Mass Balance on Four Receiving Streams

4.2.1 Cyanide Spill on the Big Blue River[9], Near Dunreith, Indiana

On January 1, 1968, a train wreck resulted in a spill of acetone cyanohydrin [$(CH_3)_2C(OH)CN$]. This compound is only stable under acidic conditions and otherwise decomposes to acetone and hydrogen cyanide. After the spill, the Indiana State Board of Health monitored the cyanide concentration at various points along the river at one-half hour intervals. Using the data presented in their reports, the total pounds of cyanide passing by each station was computed. The results are presented below and depicted graphically on Figure 4-1.

SAMPLE POINT	ESTIMATED STREAM TRAVEL TIME FROM WHERE SPILL ENTERED THE RIVER (HOURS)	MAXIMUM TOTAL CYANIDE CONCENTRATION (mg/ℓ)	TOTAL POUNDS PASSING SAMPLING STATION
Carthage	36	15.6	1,600
Morristown	50	7.8	990
Shelbyville	82	1.8	770
State Road 44	90	1.0	730

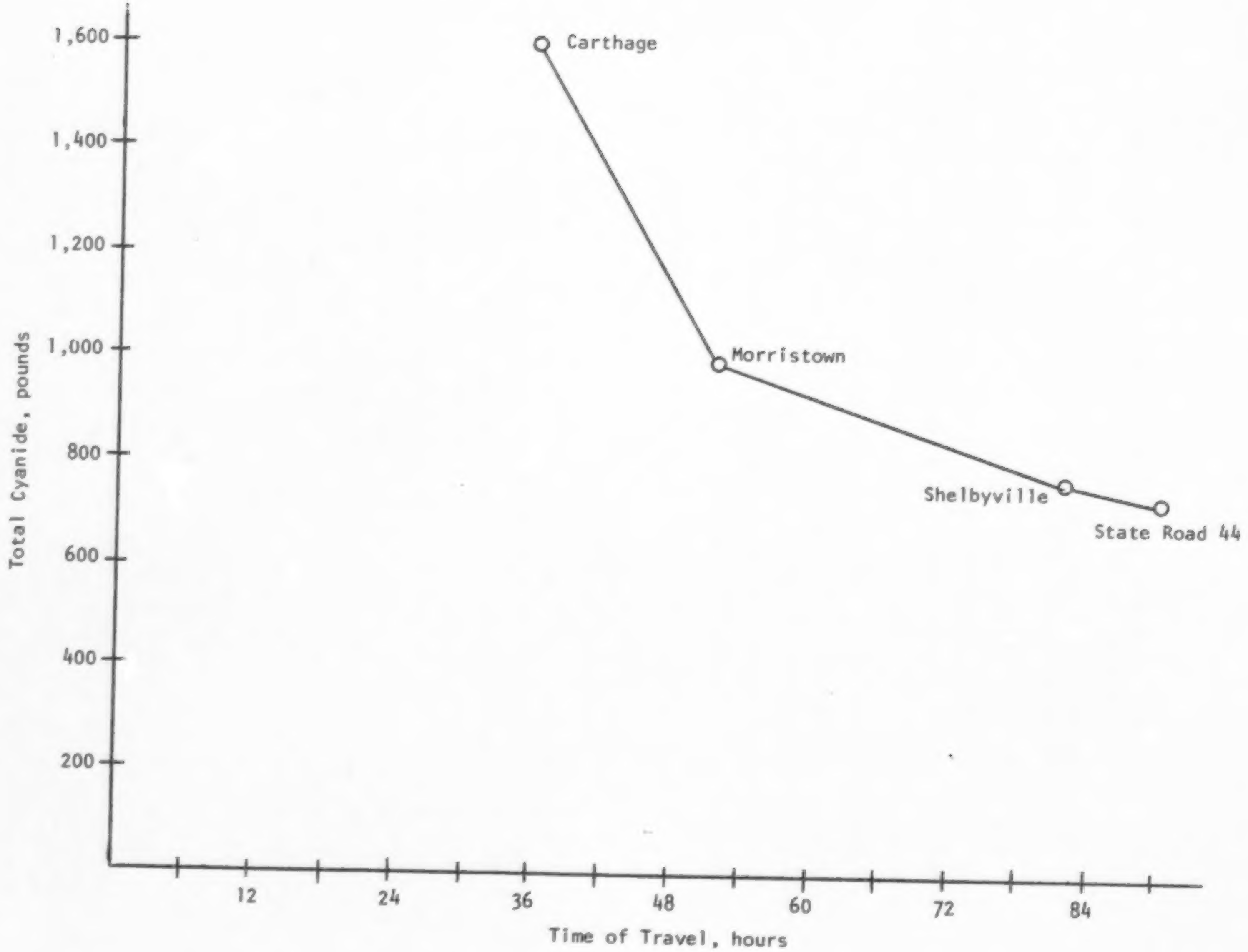


FIGURE 4-1

CYANIDE DECAY IN BIG BLUE RIVER AFTER CYANIDE SPILL

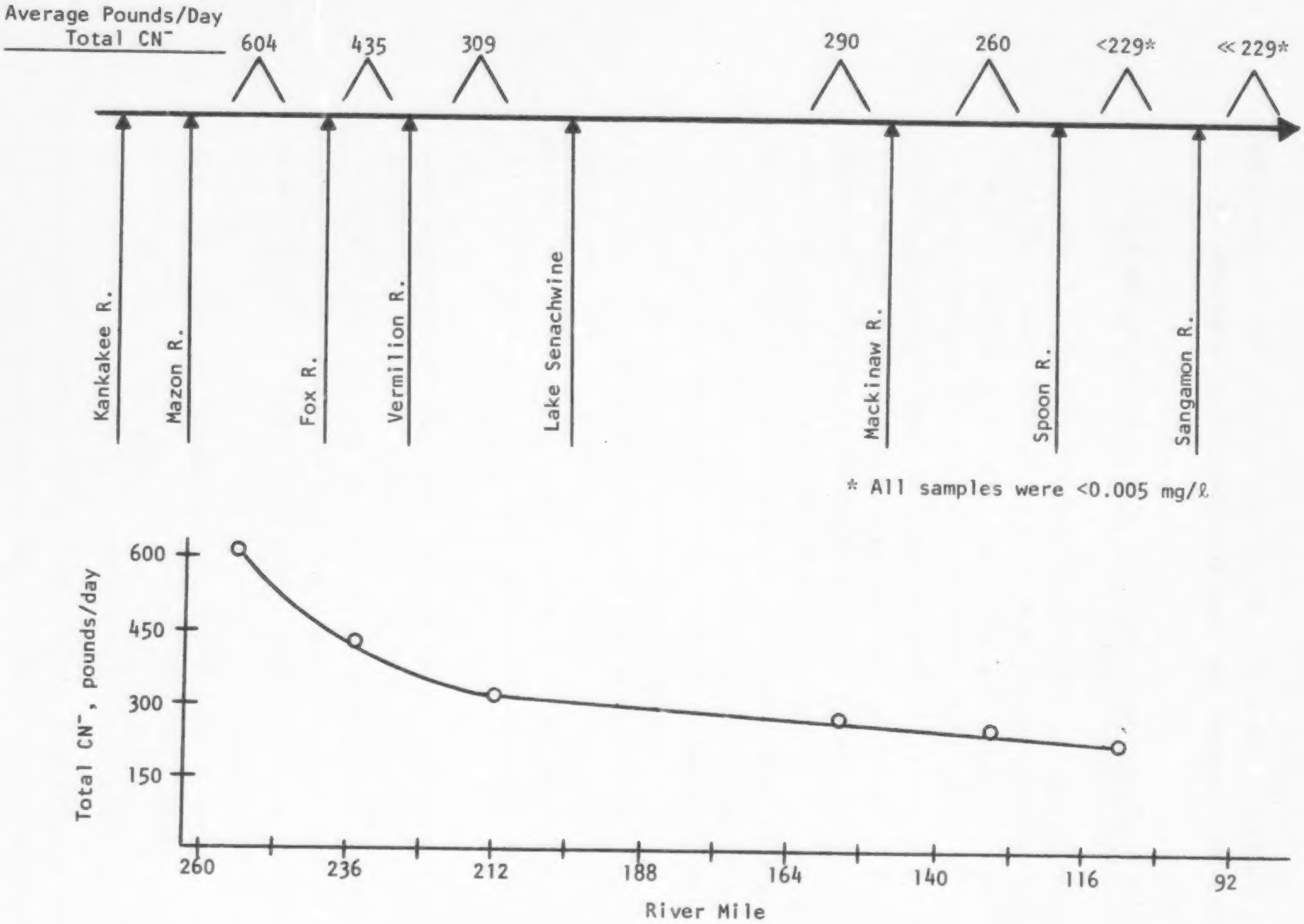
In a period of 54 hours of stream travel, 54% of the total cyanide was unaccounted for and presumed to be degraded or volatilized.

4.2.2 Illinois River Study by the U.S. Environmental Protection Agency

Another method of ascertaining cyanide decay in river systems is the examination of a mass balance with time. Water surveys which evaluate the water quality in segments of the river provide sufficient information for such a computation. The Illinois District Office of the U.S. EPA conducted a survey of the water quality in the Illinois River waterway from the Des Plaines River-Kankakee River confluence to below the city of Beardstown[10]. Twenty-six stations in 190 miles were sampled during the latter part of November, 1973. Cyanide concentrations were reported for each of these stations, and thus characterized the water quality for a continuous segment of the river. Values reported in various stretches of the river were averaged to eliminate analytical scatter and to facilitate calculation of the mass balance. Flow data for the survey period was averaged and the total pounds of cyanide calculated based on these average flow rates and total cyanide concentrations.

Because adequate water quality data for the tributaries, such as the Fox River, were not available, their contribution to the cyanide levels was assumed to be negligible. This assumption results in a conservative decay rate for the cyanide because there are some significant quantities of cyanide added to the Illinois River.

The results of this study are presented in Table 4-2 and graphically presented in Figure 4-2.



* All samples were <0.005 mg/ℓ

FIGURE 4-2

CYANIDE MASS BALANCE
1973 -- U.S. EPA DATA
ILLINOIS RIVER

TABLE 4-2

CYANIDE LEVELS IN THE ILLINOIS RIVER

RIVER MILE SECTION SAMPLED	RANGE OF TOTAL CYANIDE CONCENTRATIONS MEASURED* (mg/ℓ)	AVG. TOTAL CYANIDE CONCENTRATION (mg/ℓ)	CALCULATED TOTAL CYANIDE LOADING (lb/day)
264-246	0.022- 0.029	0.025	604
241-229	0.008- 0.015	0.012	435
220-205	0.005- 0.014	0.008	309
167-151	<0.005- 0.011	0.007	290
147-125	<0.005- 0.008	0.006	260
118-100	<0.005-<0.005	<0.005	<229
95- 81	<0.005-<0.005	<0.005	--

*Total cyanide measured by U.S. EPA procedure.

The pounds per day of total cyanide was reduced from 604 to 229, a decrease of 62% in a 150-mile stretch of the river.

4.2.3 Chicago River System Survey by the U.S. Environmental Protection Agency

During 1973, the Illinois District Office of the U.S. EPA performed an extensive sampling program on the Lower Des Plaines River and Chicago River System[12]. In this river segment, the following major dischargers were sampled:

Caterpillar Tractor -- Joliet
Commonwealth Edison,
  Will County Station -- Joliet
U.S. Steel -- Joliet
Texaco Refinery -- Lockport
Union Oil Refinery -- Lemont
Mobil Oil Refinery -- Joliet
Stepan Chemical -- Elwood
Joliet Municipal
  Treatment Plant -- Joliet

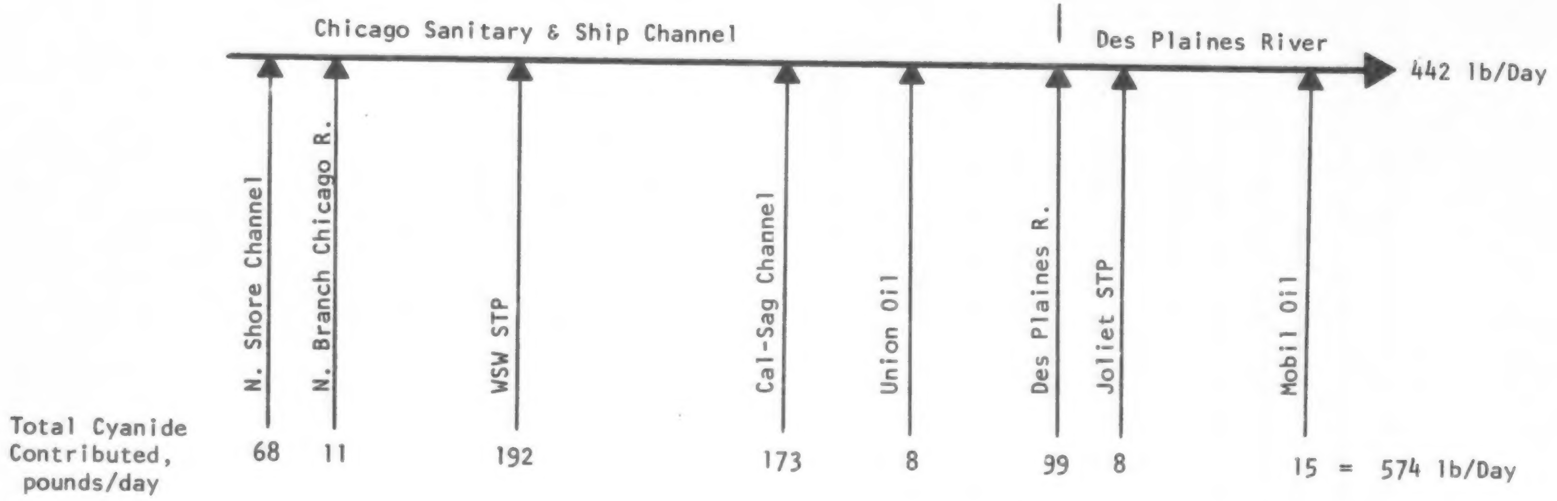
Of these dischargers, only three of them were found to be discharging cyanide in quantities greater than 3 lb/day: Mobil, Union, and the Joliet Municipal Treatment Plant.

In addition to sampling each of the above dischargers during 1973, river samples were collected and analyzed on six different periods from April to November 1973. An average total cyanide concentration was calculated for various river segments using an averaging method also utilized for the preceding water survey. The mean flow rates for 1973[11] were utilized for each stretch of the river to compute the pounds of total cyanide present. The results for each river section are presented in Figure 4-3. Based on the data presented, there appears to be an average reduction or decay of 23% in the pounds of cyanide as the water travels to the confluence of the Kankakee River. This, of course, assumes that all major cyanide inputs have been accounted for, which is a conservative estimate.

4.2.4 Chicago River System Survey to MSDGC

On August 5, 6, and 7, 1974, the Metropolitan Sanitary District of Greater Chicago performed a stream survey on the Chicago and Illinois River Systems, which was the same area analyzed by the U.S. EPA. At the confluence of the Fox River and again below Hennepin, Illinois, MSD observed an increase in the cyanide concentration in the Illinois River. This is quite contrary to the U.S. EPA study discussed previously in which no increase in cyanide occurred in these river segments. The U.S. EPA study included many more samples and therefore was considered more representative of the true water quality. Since no data concerning cyanide concentrations in the Fox River and the dischargers around Hennepin were available, MSD's survey information as far as the Fox River was all that was used.

To determine the mass balance for this river segment required information on flow rates and major contributors. Flow data for August 5, 6, and 7, 1974, were averaged for each river segment to calculate total pounds per day of cyanide.


Chicago Sanitary & Ship Channel
Des Plaines River
442 lb/Day
N. Shore Channel
N. Branch Chicago R.
WSW STP
Cal-Sag Channel
Union Oil
Des Plaines R.
Joliet STP
Mobil Oil
Total Cyanide Contributed, pounds/day
68
11
192
173
8
99
8
15 = 574 lb/Day

	Total Cyanide pounds/day
Average Discharged	574
Average at Confluence to Kankakee River	442
% Reduction in Total Cyanide	23%

FIGURE 4-3

CYANIDE MASS BALANCE
1973 -- U.S. EPA DATA
CHICAGO RIVER SYSTEM

Total cyanide concentrations for the tributaries not sampled in 1974 were obtained from 1972 total cyanide values reported by MSDGC[7]. The average total cyanide concentration for January through August, 1974, were utilized for the Calumet and North Side sewage treatment plants (STP's). For the West-Southwest STP effluent, the cyanide concentration was calculated based on upstream and downstream concentrations. Cyanide levels for the refineries were obtained from their August, 1974, monthly operating reports, while the Joliet STP's total cyanide level was obtained from the U.S. EPA load allocation study[12]. The results for each river segment are presented in Figure 4-4.

According to Figure 4-4, a cyanide reduction of 35% occurred by the time the water reached River Mile 270-245. This reduction is based on the assumption that the Kankakee and Mazon Rivers contain no cyanide.

4.3 Determination of the Cyanide Decay Rate

The amount of data available to perform mass balances on cyanide in any waterways is extremely limited. However, the four studies presented in the previous section strongly suggest that cyanide decay does indeed occur in receiving streams. If one assumes that cyanide decay follows the same pattern as biochemical oxygen demand (BOD) decay, then a decay constant can be computed. In a first-order reaction, the rate of removal is proportional to the remaining concentration, or:

$$\frac{-dL}{dt} = kL$$

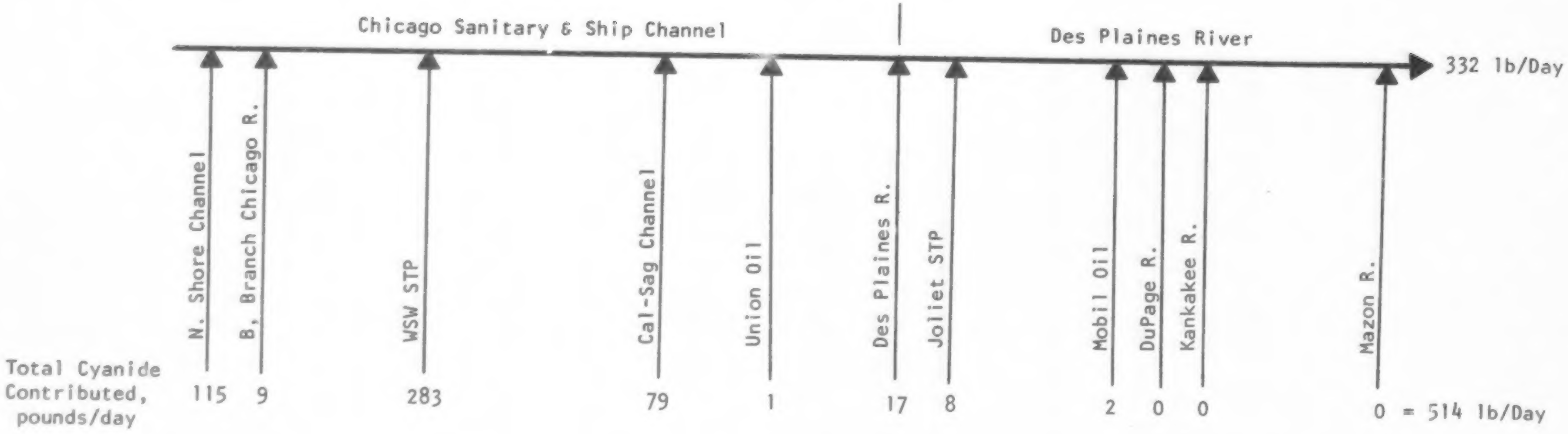
or

$$\ln\left(\frac{L_t}{L}\right) = -kt$$

where

L_t -- Pollutant loading at time t

L -- Initial pollutant loading


Chicago Sanitary & Ship Channel
Des Plaines River
332 lb/Day
N. Shore Channel
B, Branch Chicago R.
WSW STP
Cal-Sag Channel
Union Oil
Des Plaines R.
Joliet STP
Mobil Oil
DuPage R.
Kankakee R.
Mazon R.
Total Cyanide Contributed, pounds/day
115
9
283
79
1
17
8
2
0
0
0 = 514 lb/Day

	Total Cyanide pounds/day
Average Discharged	514
Average Found Between River Mile 270-245	332
% Reduction in Total Cyanide	35%

FIGURE 4-4

CYANIDE MASS BALANCE -
1974 -- MSDGC DATA
CHICAGO RIVER SYSTEM

t -- Time

k -- Constant

Because of the dilution influence as the cyanide travels downstream, pounds of cyanide per day will be used instead of cyanide concentration. This simplifying assumption will result in a smaller calculated decay rate than if concentration values were utilized.

The following values for "k" were calculated for the four mass balances presented:

STUDY	"k"	ASSUMPTIONS
Dunreith, Indiana	0.35	Calculated for river between Carthage and State Road 44
U.S. EPA study on Illinois River	0.14	River velocity -- 20 mi/day River mile initial -- 250 River mile final -- 133
U.S. EPA study on Chicago River System	0.11	River velocity -- 15 mi/day River mile initial -- 315 (WSW STP) River mile final -- 280
MSDGC study on Chicago and Illinois Rivers	0.12	River velocity -- 15 mi/day River mile initial -- 315 (WSW STP) River mile final -- 260

The Dunreith, Indiana study showed a much faster decay rate for cyanide, as evidenced by the value for constant "k". This could be attributed to the fact that only simple cyanides were present; whereas in the other three studies, the amount of simple cyanide was probably much less. MSD reported[7] that in their water survey the complexed cyanide accounted for 70-96% of the total cyanide present along the entire river.

4.4 Conclusions

Because cyanide removals across biological treatment systems have been reported, decay of cyanide in natural waters was also expected. Only a limited amount of data has been compiled regarding cyanide levels in rivers; however, four water quality studies were reported in which sufficient data was available for calculation of cyanide mass balances. These four studies indicated that degradation of cyanide in streams does indeed occur. Therefore, the impact on water quality must be adjusted for the cyanide degradation rate. In other words, the effect of a cyanide discharge diminishes with time of travel, or distance downstream. In evaluating the benefits of the standard, the decay rate of cyanide must be utilized in establishing the "critical segment", or stretch of river that is out of compliance.

Chapter 5

ESTIMATION OF BENEFITS AND COSTS OF REGULATION

5.1 Introduction

The purpose of establishing both effluent and water quality standards is maintenance of water quality at some specified level. The 1972 Amendments to the Clean Water Act established as their objective:

> "...to restore and maintain the chemical, physical, and biological integrity of the nation's waters."

This goal has been widely interpreted as a requirement for standards which protect indigenous aquatic life and permit secondary contact recreation, such as boating and fishing. Water of this quality will generally be sufficient to protect other uses, such as public water supply, agricultural and industrial use.

In establishing effluent and water quality standards, it is important to evaluate the costs and benefits of compliance. While compliance costs may be readily calculated, the benefits to be gained are very difficult to assess. The benefits of improved water quality are considered public goods, and as such do not have a readily perceivable value. By considering the public good, water quality as a complement to a private good such as recreational activities, benefits for changes in quality can be evaluated. Karl-Gorän Mäler[13] demonstrated that such an approach is economically viable and meaningful. This approach implies that the demand for various levels of water quality is related to the consumption of recreational activities, and thus people who do not use streams for recreation do not benefit from water quality improvements. Conversely, deterioration of water quality primarily affects the stream users.

In this study of cyanide, the benefits were measured totally by the recreational value of various Illinois rivers. For many pollutants, there are other benefits to be gained, such as

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drinking water quality (taste and odor), industrial water treatment (de-ionizing and filtration), and other recreational benefits (swimming). Because of the extremely low concentrations at which cyanide is toxic to fish, none of the other uses of these waters are influenced by the cyanide.

The acute effects of the various forms of cyanide are well established; however, there is very little data available concerning the chronic effects of these same compounds. This dearth of data was recognized by the National Technical Advisory Committee (Interim Report, 1967) when they presented the following recommendation[14]:

> Concentration of materials with noncumulative toxic effects should not exceed 1/10 of the 96-hour TL_m at any time or place.

As more information regarding these effects becomes available, water quality standards can be more accurately established as opposed to relying on a simplified decision rule.

Within this section, the methodology for estimating the primary costs and benefits of alternative standards is presented. Utilizing this procedure, values for the costs and benefits are computed and evaluated in terms of their economic implications. Evaluation of the benefits is accomplished in five steps.

Step 1 consists of identifying those cyanide dischargers and water segments which are impacted by the regulation. The available data on the chronic and toxic concentrations associated with various Illinois fish species will be summarized in Step 2. In Step 3, the probability of an occurrence of chronic or toxic effects is determined for the affected segment. The fourth step estimates the actual costs of such an occurrence for these water segments based on their existing usage, and Step 5 measures the incremental gain of reduced costs achieved by a standard change.

The treatment costs associated with the alternative regulations are estimated for the four major discharge segments, refining, steel, municipalities, and plating. The costs of compliance are then compared to the incremental benefits gained.

5.2 Areas of Cyanide Impact

The cyanide problem within the State of Illinois appears to be a regional problem for the industrialized Chicago metropolitan area. There are a few other dischargers and water quality segments affected, but without additional data, it is difficult to quantify their significance with regard to the proposed standard modification. Therefore, Planning Area 2 is considered the region for analysis of costs and benefits. Within this region, there is concern regarding the Calumet, Des Plaines, Illinois, and Fox Rivers. These systems represent the primary waterways in this area and the cyanide dischargers and water quality are of special concern for these rivers.

To more precisely describe Planning Region 2, Table 5-1 was prepared which categorizes the counties, waterways, and dischargers which are the basis of our analysis. Although some counties, such as LaSalle and Kendall, contain no cyanide dischargers, the river segments which pass through them may be affected by upstream conditions and thus are included in the analysis. Another important reason for their inclusion relates to the value of their streams as an alternative to more polluted waters of a neighboring county. Thus, the entire planning region (with the exception of two counties) is important in the overall benefit analysis.

5.3 Cyanide Toxicity

The toxic and chronic effects of cyanide compounds vary considerably depending upon such factors as pH, dissolved oxygen level, and complex formed. Extensive testimony regarding toxicity of cyanide was presented before the Illinois Pollution

Table 5-1

DESCRIPTION OF PLANNING AREA 2

Impacted Stream	Discharger	County
Fox River	Fox River Grove	McHenry
	East Dundee	Kane
	West Dundee	Kane
	Elgin	Kane
	Aurora	Kane
Calumet River	Calumet (MSDGC)*	Cook
Des Plaines -- Illinois River	West-Southwest (MSDGC)	Cook
	Union Oil	Cook
	Texaco	Will
	Mobil	Will
	Joliet Sanitary District	Will
North Branch Chicago River	Northside (MSDGC)	Cook

* Interlake, Inc., Republic Steel, and Wisconsin Steel are dischargers to MSD (Calumet), plus Wisconsin Steel's blast furnace discharges directly to the Calumet River.

Control Board during the regulatory hearings of R74-15 and -16. and the findings utilized in this analysis are taken from those presentations.

A summary of the acute and chronic effects of various cyanide complexes, which is provided in this section, denotes the concentration range of potential harm to aquatic biota. The types and levels of cyanides which are found in Illinois waterways can thus be evaluated as to their impact on fish and, therefore, water quality. After identifying the cyanide forms which occur in the streams, the cyanide levels are chosen at which significant changes in water quality will be observed.

5.3.1 Acute Toxic Effects of Cyanide

Cyanide toxicity can be attributed to its inhibitory powers on oxygen metabolism, according to Dr. Broderius[16]. This toxicity is the result of the action of hydrocyanic acid (HCN) on the enzyme cytochrome oxidase. It is not the cyanide ion but rather the undissociated HCN molecule which is so lethal. Therefore, the degree of hydrolysis of simple and complex cyanides is important in determining their overall toxicity[15,16]. Broderius categorized cyanides into two groups, those which are completely ionized at low concentrations (NaCN, KCN, $CdCN_2$, $ZnCN_2$, K_2CdCN_4, and K_2ZnCN_4) and the more stable ones which vary in degrees of ionization (AgCN, CuCN, $NiCN_2$, K_2CuCN_3, K_2NiCN_4, K_4FeCN_6, K_3FeCN_6, and $K_3Co(CN)_6$.

There has been limited research regarding the toxicity of metallocyanides, but it is clear that environmental factors, such as pH, are important in determining the magnitude of effects. In Table 5-2, the studies which were discussed by Broderius and Doudoroff during R74-15 and -16 hearings are summarized. The 96-hour TL_m of the alkali cyanides varied from 0.18 to 0.23 mg/ℓ as CN^-. Other metallocyanides such as $Cd(CN_4)^{-2}$ and $Zn(CN_4)^{-2}$ also were found to be as toxic as the simple cyanides, according to Table 5-2. Nickel, copper, and iron cyanides were associated with much higher lethal concentrations.

Table 5-2

SUMMARY OF ACUTE TOXICITY STUDIES

Compound Tested	TL_m Values (mg/ℓ as CN^-)				Test Organism
	pH	24 hr	48 hr	96 hr	
NaCN	6.5-7.5	0.25	0.24	0.23	Fathead minnows
KCN	--	0.28	--	--	Bluegills
KCN		--	--	0.18	
$(CdCN_4)^{-2}$	--	0.23	0.21	0.17	Fathead minnows
$(ZnCN_4)^{-2}$	8.0	0.20	0.19	0.18	Fathead minnows
$(NiCN_4)^{-2}$	8.0	--	1,200	730	Fathead minnows
$(NiCN_4)^{-2}$	7.5	--	36	21	Fathead minnows
$CuCN_2^-$	--	--	4	--	Bluegills
$Fe(CN_6)^{-4}$	--	--	10*	--	Fathead minnows
$Fe(CN_6)^{-4}$	7.2-7.3	1-2**	--	--	--

* Was not fatal in 48 hr.

** Burdick and Lipschuetz showed fatal in New York stream with bright sunlight.

The lethal toxicity to fish from these simple and complex cyanides is directly related to the degree of dissociation. In most receiving streams, any CN^- that dissociates from a simple alkali or complex cyanide will form the toxic hydrocyanic acid (HCN).

The minimum lethal threshold concentrations or the concentration barely tolerated by individuals of average resistance for indefinitely prolonged exposure is perhaps a better indicator of the true acute toxicity levels. Dr. Broderius[17] reported minimum lethal threshold concentrations for various fish species as follows:

Fish Species	Temp, °C	Minimum Lethal Threshold Concentration of Hydrocyanic Acid (HCN), mg/ℓ
juvenile brook trout	10	0.080
yellow perch	21	0.105
largemouth bass	25	0.095
black crappe	25	0.100
bluegill	25	0.120
wild fathead minnows	25	0.170
laboratory reared fathead minnows	25	0.115

The above results are reported based on the hydrocyanic acid (HCN) concentration. These results led Broderius to state,

> "... it can be concluded that free cyanide concentrations near 0.100 mg/ℓ as CN^- have proven eventually fatal to a high percentage of many cold and warm water fishes..."

The fate of the complex cyanides, especially the ferro- and ferri-cyanides, in the receiving streams is a subject where more actual field work is needed. If the iron cyanides are indeed photochemically decomposed, as reported in the Burdick and Lipschuetz study, then effluent standards on total cyanide of 1 to 2 mg/ℓ cannot be justified.

Dr. Broderius also reported preliminary results which indicated iron cyanides are readily decomposed by sunlight, and therefore could be potentially as toxic as the simple cyanides.

5.3.2 Chronic Effects of Cyanide

The effects of long-term exposure to sublethal concentrations have not been thoroughly investigated. However, Broderius testified[17],

> Contrary to positions proposed in different statements presented before this board, I can definitely state that free cyanide is indeed a chronic toxicant.

Broderius has found free cyanide to have the following chronic effects:

Indicator	Free Cyanide Concentration, mg/ℓ	Comments
Growth	> 0.045	"Marked" effect on growth at levels above 0.045 mg/ℓ
Growth	> 0.030	Fathead minnows, newly hatched fry
Egg production	≥ 0.020	"Significantly" depressed fecundity
Egg fertility	≥ 0.040	"Significantly reduced"

Based on these findings, Broderius calculated "that at about 0.012 mg/ℓ HCN effective reproduction was approximately 50% of controls". The procedure for this calculation was not presented, but presumably was based on a projection of the following two points:

Free Cyanide Concentration, mg/ℓ	% of Control, Effective Reproduction
0.040	8
0.025	20

While extrapolating actual laboratory studies to natural populations in waterways is in itself suspect, extrapolation of a "calculated" effect based on two preliminary laboratory studies is not creditable. Until additional investigations are completed; however, these results represent the best available information.

5.3.3 Type of Cyanide in Illinois Waterways

Based upon the differences in the acute toxicity between free, simple, and complex cyanides, there appears to be justification for more than a total cyanide standard. However, one of the greatest concerns with separate limitations for simple and total cyanide is the lack of information regarding photodecomposition rates of the complex cyanides in natural waters. There is a possibility that photodecomposition in the river could result in the formation of the very toxic HCN. Data on the form of cyanides in Illinois waterways is almost nonexistent, and there is also little information on the type of cyanide found in the industrial and municipal dischargers.

MSDGC performed a water sampling program from August 5 to 7, 1974, in which 15 samples in the Sanitary and Ship Canal, Des Plaines River, and Illinois River down to Peoria were collected and analyzed for simple and total cyanide. Based on MSDGC's analytical procedure, the "simple" cyanide method detects all types except iron and cobalt cyanides. The simple cyanide level was below 0.005 mg/ℓ for all 15 samples collected by MSDGC, while the complex cyanide ranged from 0.009 to 0.033 mg/ℓ. This finding suggests that a substantial portion of the cyanide present in the Chicago and Illinois river systems is the complex iron cyanide. To confirm this data, a one-year sampling period for every river where a potential cyanide problem exists would be required.

MSDGC's data represents the only information available regarding levels of simple cyanide in the waterways. To ascertain the potential toxic and chronic effects, one must assume that their (MSDGC) data is indicative of existing water quality in the Des Plaines-Illinois river system at present discharge levels. Since no data are available regarding the simple cyanide levels typical in other streams, a ratio of simple to complex cyanide was assumed for our study. Effluent data of industrial dischargers indicated that approximately 50% of the effluent cyanide was in the simple form. Therefore, in estimating the simple cyanide concentrations in streams, 50% of the total concentration was considered simple cyanide.

5.3.4. Toxic Cyanide Levels for Benefit Analysis

The two cyanide concentrations which represent the occurrence of acute and chronic effects must be designated to perform the benefit analysis. Depending upon the cyanide form and fish species, cyanide concentrations can be identified which have lethal or long-term effects.

Data indicating the acute cyanide level was based on bioassays performed by MSDGC and the values summarized in Table 5-2. The Metropolitan Sanitary District of Greater Chicago performed bioassays using the effluent from their treatment plants. These effluents contained not only cyanide but trace metals, ammonia, and other constituents which might be expected to react synergistically. According to MSDGC's results, 100% survival of fathead minnows during 96 hours occurred with total cyanide levels of 0.004 to 0.131 mg/ℓ The form of the cyanide was approximately 0.0029 to 0.0329 mg/ℓ simple at Calumet and 0.002 to 0.005 mg/ℓ at West-Southwest. Their experiments indicated no acute effects up to 0.03 mg/ℓ simple cyanide occurred even in the presence of potentially synergistic materials.

In Table 5-2, typical 96-hour TL_m values for simple cyanides, such as potassium and sodium cyanide, were presented for bluegills and minnows. The lowest concentration associated with acute effects was 0.18 mg/ℓ for the bluegill, which was considered as sensitive as other Illinois fish species.

Broderius concluded that concentrations near 0.1 mg/ℓ free cyanide would eventually be toxic to most fish. In this study, 0.1 mg/ℓ simple cyanide was selected to represent the acute concentration for all fish in Illinois waterways.

Broderius reported chronic effects occur from exposures to free cyanide concentrations from 0.020 mg/ℓ to 0.045 mg/ℓ for various indicators of chronic effects. In our analysis, a value of 0.025 mg/ℓ simple cyanide was selected as the level where chronic effects will occur for all fish in the Illinois waterway.

5.4 Estimation of Affected Water Segments

Dischargers of cyanide have a variable impact on water quality, depending upon fluctuations in river volume, effluent flow, and cyanide concentration. Therefore, any attempt to estimate water quality changes is associated with a probability of occurrence dependent upon these variables. By considering the possible implementation of several standards, the probable cyanide concentration discharged is modified. Combinations of these concentrations (quantities) and river flow yield a receiving stream cyanide level which indicates the affected river segments and the probability of these occurrences.

First, in this section is the description of the stream flows, effluent quantities, and methodology utilized in determining affected segments. Then, several possible effluent regulations are evaluated as to their effect on levels of cyanide discharged and water quality. A combination of probabilities, impacted river segments, and possible standards provide a wide range of quality levels for the aquatic environment.

5.4.1 Cyanide Levels in Water Segments

In Planning Area 2, there are four waterways which receive the majority of cyanide discharged. The Fox River, Des Plaines River, Chicago-Illinois River, and Calumet-Cal Sag Channel are located in populated and industrialized areas which contribute significantly to cyanide levels in the water.

These four rivers were utilized to determine the effects of river flow and effluent cyanide quantities on cyanide concentration. The methodology followed in such a determination relied on information regarding point source discharges obtained in Chapter 3 and flow data from the Illinois Water Survey. Since the impact of cyanide discharged depends upon the presented form, and river flow, the probability associated with each factor was needed to determine the frequency of any set of specified conditions. The river volumes used to demonstrate water quality effects represented low flows occurring 10% of the time and that of 0.2% frequency (seven-day, 10-year low flow). If no harmful cyanide concentration was attained during such low flows, then the possibilities of any water quality violation ever occurring were considered negligible.

Average and maximum effluent quantities were calculated for each discharger as well as the probability of occurrence. This probability reflected concentration frequency data tabulated in Chapter 3. The form of these cyanides, simple versus complex, is also important for these dischargers because of the difference in toxic effects. Where the percent simple cyanide was not known, which is the case for most dischargers, a value of 50% simple was assumed. The 50% simple cyanide was also assumed to exist in the receiving streams, because of the lack of actual data. As each cyanide discharge entered the receiving stream, the concentrations were calculated and decay factors estimated in Chapter 4 were applied to downstream values. Thus, the cyanide concentration pattern in the river was determined for the entire river segment for two flow conditions and two cyanide discharge conditions. Where the water quality concentration exceeded 0.025 mg/ℓ simple cyanide or 0.1 mg/ℓ simple cyanide, that river segment was designated an affected area.

These factors which were utilized are summarized below:

Variable	Number of Levels	Type of Levels
Cyanide Quantity	2	maximum/average pounds per day
River Flow	2	10%/0.2% frequency of low flow volume
Form of Cyanide	1	50% -- complex form 50% -- simple form

5.4.2 Alternative Standards Considered

The probability of attaining certain levels of cyanide in the discharge is related to the effluent standard in existence. As more stringent standards are imposed, the probability distribution narrows or, in other words, there is a reduced probability associated with excursions from the standard.

Several standards have been proposed by the refining and steel industry regarding total and simple cyanide levels in the effluent. Five alternative regulations were considered in the analysis of affected water segments, benefits, and treatment costs. Based on the results of this analysis of the five following alternatives, an optimum standard may be ascertained:

	Not to be Exceeded Based on
1. 0.025 mg/ℓ total cyanide	24-hr Composite
2. 0.025 mg/ℓ total cyanide	Monthly Average
3. 0.050 mg/ℓ total cyanide	Monthly Average
4. 0.100 mg/ℓ total cyanide	Monthly Average
5. 0.200 mg/ℓ total cyanide	24-hr Composite

All of the proposed standards are defined in terms of total cyanide; however, it was assumed that 50% of the cyanide occurred in the simple form. Thus, a daily maximum of 0.2 mg/ℓ total corresponded to 0.1 mg/ℓ simple cyanide standard. This assumption appeared reasonable based on the data submitted by the refineries, steel industry, and MSDGC. The selection of these alternatives was based on analytical considerations, enforcement viability, and realization of industrial discharge characteristics. A detailed discussion regarding this selection is presented in Chapter 6 of the report.

5.4.3 Identification of Impacted Water Quality Segements

Utilizing the effluent standards and stream flow conditions previously discussed, the river segments were identified in which chronic or acute effects would occur. The number of river miles in which the total cyanide concentration exceeded 0.2 mg/ℓ or 0.05 mg/ℓ were tabulated for three river systems. These three systems represented the heaviest concentration of cyanide dischargers, and thus were expected to indicate the degree of water quality afforded by each alternative standard.

Tables 5-3, 5-4, and 5-5 summarize the results for the Fox River, Chicago-Illinois River system, and the Calumet River-Cal Sag Channel. These results are specified according to the standard, toxic effects, stream flow condition, and cyanide discharge levels. For each combination of stream and effluent conditions, there is an associated chance of occurrence. Thus, the number of affected miles is associated with a probability of incidence. In the appendix to Chapter 5, the methodology utilized to obtain these probabilities is explained.

The Fox River system appears to be minimally affected by effluent standards up to 0.05 mg/ℓ total cyanide as a monthly average. At maximum discharge rates and low flow conditions, a 0.10 mg/ℓ total cyanide monthly average standard would result in chronic affects in approximately forty miles of the Fox River.

Table 5-3

AFFECTED WATER QUALITY SEGMENTS IN THE FOX RIVER

Effluent Standard Imposed	Chronic or Acute Effects	Number of Miles Affected			
		Condition 1	Condition 2	Condition 3	Condition 4
0.025 mg/ℓ total cyanide in 24-hr composite	Chronic	0	0	0	0
	Acute	0	0	0	0
0.025 mg/ℓ total cyanide monthly average	Chronic	0	0	0	0
	Acute	0	0	0	0
0.05 mg/ℓ total cyanide monthly average	Chronic	0	0	0	50
	Acute	0	0	0	0
0.1 mg/ℓ total cyanide monthly average	Chronic	0	0	18	68
	Acute	0	0	0	0
0.2 mg/ℓ total cyanide in 24-hr composite	Chronic	0	0	0	20
	Acute	0	0	0	0
Existing Discharge Conditions	Chronic	0	0	18	68
	Acute	0	0	0	0

Condition 1 = Average pounds per day discharged and low flow occurring 10% of the time.

Condition 2 = Average pounds per day discharged and low flow occurring 0.2% of the time.

Condition 3 = Maximum pounds per day discharged and low flow occurring 10% of the time.

Condition 4 = Maximum pounds per day discharged and low flow occurring 0.2% of the time.

Table 5-4

AFFECTED WATER QUALITY SEGMENTS IN THE CHICAGO-ILLINOIS RIVER SYSTEM

Effluent Standard Imposed	Chronic or Acute Effects	Number of Miles Affected			
		Condition 1	Condition 2	Condition 3	Condition 4
0.025 mg/ℓ total cyanide in 24-hr composite	Chronic	0	0	0	0
	Acute	0	0	0	0
0.025 mg/ℓ total cyanide monthly average	Chronic	0	0	43	56
	Acute	0	0	0	0
0.05 mg/ℓ total cyanide monthly average	Chronic	0	0	43	77
	Acute	0	0	0	0
0.10 mg/ℓ total cyanide monthly average	Chronic	0	0	69	77
	Acute	0	0	0	0
0.20 mg/ℓ total cyanide in 24-hr composite	Chronic	0	0	43	80
	Acute	0	0	0	0
Existing Discharge Conditions	Chronic	0	0	69	87
	Acute	0	0	0	0

Condition 1 = Average pounds per day discharged and low flow occurring 10% of the time.

Condition 2 = Average pounds per day discharged and low flow occurring 0.2% of the time.

Condition 3 = Maximum pounds per day discharged and low flow occurring 10% of the time.

Condition 4 = Maximum pounds per day discharged and low flow occurring 0.2% of the time.

Table 5-5

AFFECTED WATER QUALITY SEGMENTS IN THE CALUMET RIVER-CAL SAG CHANNEL

Effluent Standard Imposed	Chronic or Acute Effects	Number of Miles Affected			
		Condition 1	Condition 2	Condition 3	Condition 4
0.025 mg/ℓ total cyanide in 24-hr composite	Chronic	0	0	0	0
	Acute	0	0	0	0
0.025 mg/ℓ total cyanide monthly average	Chronic	0	6	2	2
	Acute	0	0	0	8
0.05 mg/ℓ total cyanide monthly average	Chronic	0	14	25	19
	Acute	0	0	0	8
0.10 mg/ℓ total cyanide monthly average	Chronic	21	21	21	19
	Acute	0	6	6	8
0.20 mg/ℓ total cyanide in 24-hr composite	Chronic	6	27	27	19
	Acute	0	0	0	8
Existing Discharge Conditions	Chronic	21	21	21	19
	Acute	0	6	6	8

Condition 1 = Average pounds per day discharged and low flow occurring 10% of the time.

Condition 2 = Average pounds per day discharged and low flow occurring 0.2% of the time.

Condition 3 = Maximum pounds per day discharged and low flow occurring 10% of the time.

Condition 4 = Maximum pounds per day discharged and low flow occurring 0.2% of the time.

The Chicago-Des Plaines-Illinois River system is not impacted under average discharge conditions at any standard and any low flow. However, the maximum discharge rates appear to affect long stretches (up to 87 miles) of this water segment at low flows. The primary reason for such impact at maximum rates is the West-Southwest plant of the MSDGC. According to data of MSDGC[7], the maximum loading is five times greater than the average at West-Southwest.

In Table 5-5, the effects of cyanide dischargers (Wisconsin Steel and MSDGC's Calumet plant) on the Calumet River-Cal Sag Channel are tabulated. The existing discharges result in cyanide concentrations at chronic and acute levels in the waterway for a major portion of the stream. The reason for such problems relates to the small amount of water available for mixing at 10% and 0.2% low flow frequencies and present cyanide quantities discharged. All effluent standards proposed improve the water quality with the exception of the 0.10 mg/ℓ total cyanide monthly average.

These tables represent the most severe impact on water quality and are presented to provide a perspective on the extent of the cyanide problem and the impact of various effluent standards. The benefit analysis is based on the data provided in these tables as approximations of the damages which may occur with various standards.

5.5 Benefits of Regulation

Regulation is a means of achieving a desired level of water quality and maintaining that level. An effluent standard cannot insure that all streams will be protected at all times because of variations in receiving streams and effluent flows. However, there are expected levels of protection which are associated with some minimal probability of damage to the environment. In this analysis, the benefits of regulation are measured as reduced probabilities of poor water quality.

Water quality is considered a public good, and thus it is difficult to assess the value of changes in its level. The market demand for water quality as a good is measured by the demand for its complementary private good, namely, recreational activity. If these goods are perfect complements, then people engaging in recreation also value water quality. Because cyanide is lethal to fish, changes in the supply of high quality fishing waters will be reflected by changes in the number of fishing trips. The demand and supply curves associated with fishing trips may be similar to that illustrated in Figure 5-1.

Utilizing a price per fishing trip and the projected annual number of trips per river, the annual recreational value of a river can be determined. As water quality is changed, the number of trips also varies. When a stream which is considered a fishing site is damaged, a fisherman will either seek an alternative site which is farther away (more expensive) or he will cease fishing. Because the cost of fishing has increased, fewer trips are made depending upon the shape of the demand and supply curves. For our analysis, the most restrictive case is assumed, that is, there are not alternative sites and fishing is discontinued. Therefore, the loss of recreational opportunities associated with a particular river is measured as the cessation of fishing along the impacted river segments.

Alternative standards have different impacts on maintaining water quality and fishing activity. Each can be evaluated according to the incremental changes associated with its enforcement.

In this section, the benefits are measured for five alternative effluent regulations. With each standard, there is an associated curve which relates the damage or recreational loss in dollars to the probability of occurrence. By measuring the incremental differences between these curves and standards, the benefits of regulation can be estimated.

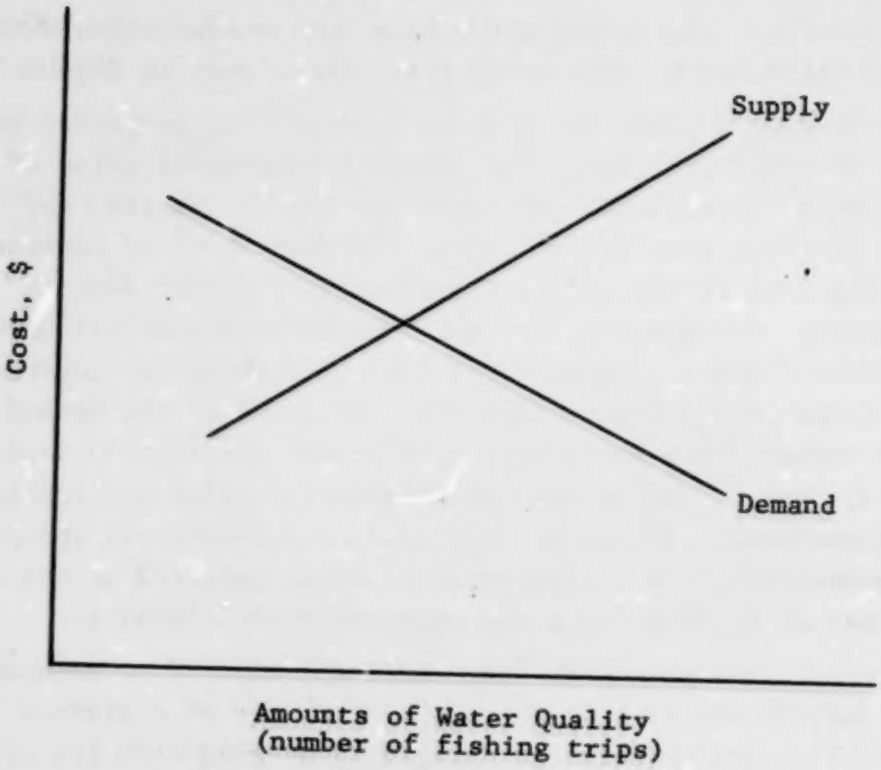

Figure 5-1

DEMAND AND SUPPLY OF WATER QUALITY

5.5.1 Fishing Activity in Illinois

Fishing activity in Illinois is closely correlated to population. Planning Area 2, which is the most densely populated, is also an important fishing region. Table 5-6 depicts the number of residents, licensed fishermen, and projected fishing trips for each state planning area. Approximately 40% of the total fishermen in Illinois live in Planning Area 2.

Survey analysis by the Illinois Department of Conservation indicated that 85% of all fishermen travel less than 50 miles from their homes to engage in this activity. Thus, the rivers in Area 2 are important potential recreational sites for resident fishermen. The usefulness of these waters is related to the number of available stream bank miles, water quality, and number of fishermen. In Table 5-7, statistics on stream miles and number of fishermen are summarized for all counties in Planning Area 2. Will, LaSalle, and Grundy Counties contain the highest number of stream miles, although the number of fishermen in these counties is not extremely large.

The actual number of fishing trips occurring within a county depends upon the accessibility of stream miles and the water quality. One of the results of pollution is a decrease in the number of fish species. Therefore, a large number of species is indicative of higher water quality and more extensive fishing. Thus, to determine the degree of fishing activity per county, an index was formulated which relates stream miles and number of species. If the number of trips per county were simply allocated according to the percentage of stream miles, the results would appear as in column 1 of Table 5-8. However, an adjustment is needed for water quality conditions. The factor utilized relates the average number of species per stream mile in the county to that of the entire planning region. Thus, those streams with above average water quality receive a greater number of trips to properly represent their quality. Depending upon the level of fishing

Table 5-6

FISHING ACTIVITY BY PLANNING AREA

Planning Area	1967 Population	1980 Licensed Fishermen	1980 Projected Fishing Trips
I	727,200	89,400	1,323,000
II	7,242,300	304,400	1,233,000
III	591,800	74,500	360,000
IV	529,400	62,400	212,000
V	232,900	29,300	134,000
VI	772,900	80,900	73,000
VII	514,700	54,500	147,000
VIII	318,800	45,800	34,000
Total	10,930,000	741,300	3,517,000

Source: Illinois Department of Business and Economic Development, Technical Appendix to the Report on Priority and Planning Elements for Developing Illinois Water Resources, May, 1970.

Table 5-7

RECREATIONAL ATTRIBUTES OF PLANNING AREA 2

County	Number of Stream Bank Miles	Number of 1967 Resident Fishermen
Cook	202	104,900
DeKalb	150	3,400
DuPage	124	9,300
Ford	24	1,400
Grundy	240	4,800
Iroquois	222	2,100
Kane	172	18,800
Kankakee	102	9,900
Kendall	126	1,500
Lake	68	54,200
LaSalle	292	12,300
Livingston	156	3,000
McHenry	210	6,900
Will	364	15,600
Total	2,452	248,100

Source: Illinois Fishing Guide, Department of Conservation, Division of Fisheries, 1970.

Table 5-8

PROJECTED FISHING ACTIVITY BY COUNTY IN PLANNING AREA 2

County	1980 Fishing Occasions in County(1)	1980 Fishing Occasions in County Adjusted for Water Quality(2)
Cook	101,500	63,800
DeKalb	75,400	88,300
DuPage	62,300	57,800
Grundy	120,600	137,800
Iroquois	111,500	92,400
Kane	86,400	115,800
Kankakee	51,200	53,400
Kendall	63,300	66,600
Lake	34,200	50,800
LaSalle	146,700	134,600
McHenry	105,500	136,500
Will	182,900	175,400

(1) Determined from:

$$\left[\begin{array}{c}\text{1980 Estimated Total}\\ \text{Fishing Occasions}\\ \text{in Planning Area}\end{array}\right] \times \left[\frac{\begin{array}{c}\text{Number of Stream}\\ \text{Miles in County}\end{array}}{\begin{array}{c}\text{Number of Stream}\\ \text{Miles in Planning Area}\end{array}}\right]$$

(2) Adjusted by Water Quality Factor,

$$\frac{\left[\begin{array}{c}\text{Average Number of Fish Species}\\ \text{in County per Stream Mile}\end{array}\right]}{\left[\begin{array}{c}\text{Average Number of Fish Species}\\ \text{in Planning Area II per Stream Mile}\end{array}\right]}$$

activity, the recreational value of waters within a particular county could be ascertained.

The Outdoor Recreation Resources Commission (ORRC) evaluated the average expenditures of fishermen in 1965 according to food, travel, equipment, licenses, and other expenses. In Table 5-9, these original values are presented, as well as 1975 values adjusted. In 1965, a river bank fisherman spent $73.63, while in 1975, the same items totalled $117.63. Since the average fisherman goes on nine trips per year, he expends $13.02 per trip. For each trip which is lost due to fish kills or reduction in numbers, there is an expected loss in recreational value. Because we are concerned with changes in recreational value of particular rivers, it is important to evaluate the existing worth. Each county segment of a particular river was determined by using the cost per trip and proportion of miles within the county. Table 5-10 depicts the value of the Fox, Des Plaines, Little Calumet, and Illinois Rivers by county segments. Any pollution effects which reduce or eliminate fishing in these areas are calculated by utilizing those values shown in Table 5-10.

5.5.2 Benefits of Alternative Regulations

5.5.2.1 Methodology Description

The feasibility of various proposed standards is based upon their associated costs and benefits. Benefits can be measured as the reduction in loss of recreational activity for various water segments. The philosophy behind such an approximation is that an effluent standard is utilized to insure a minimum probability of damage.

With each standard there is a curve which relates the damage of impacted river segments (in dollars) to the chance or probability of occurrence, such as shown in Figure 5-2. The probability of occurrence is the joint probability calculated for the stream and effluent conditions utilized in determining

Table 5-9

AVERAGE ANNUAL RIVER FISHING EXPENDITURES

Expense Item	1965 Dollars Spent	1975 Dollars Spent (1)
Food	$12.01	$ 20.78
Auto	14.10	25.38
General	5.67	8.62
Fishing Equipment	11.41	17.34
License	2.40	2.40
Bait, etc.	26.62	40.46
Other	1.42	2.16
Total	$73.63	$117.14

Note: (1) The January, 1975 Consumer Price Index values for Commodities, Food, and Gasoline of 152, 173, and 180 were used to obtain 1975 values.

Source: Outdoor Recreation Resources Commission Report, U.S. Department of Interior, 1965.

Table 5-10

RECREATIONAL STREAM VALUE*
(Dollars per Mile per Year)

County	Fox River	Des Plaines River	Illinois River	Little Calumet River
Cook	$ --	$10,990	$ --	$4,710
DeKalb	--	--	--	--
DuPage	--	7,130	--	--
Grundy	--	--	14,920	--
Iroquois	--	--	--	--
Kane	22,220	--	--	--
Kankakee	--	--	--	--
Kendall	20,560	--	--	--
Lake	24,280	18,680	--	--
LaSalle	14,950	--	5,600	--
McHenry	22,430	--	--	--
Will	--	4,410	--	--

$$\text{\$/mile} = \begin{array}{c}\text{Number of}\\ \text{Fishing Trips}\\ \text{in County}\end{array} \times \frac{\text{Stream Index}}{\text{County Index}} \times \frac{1}{\begin{array}{c}\text{Stream Miles}\\ \text{in County}\end{array}} \times \frac{\$}{\text{Fishing Trip}}$$

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* A value of $4,000 per mile was utilized for the Calumet River and Cal Sag Channel as a minimum value.

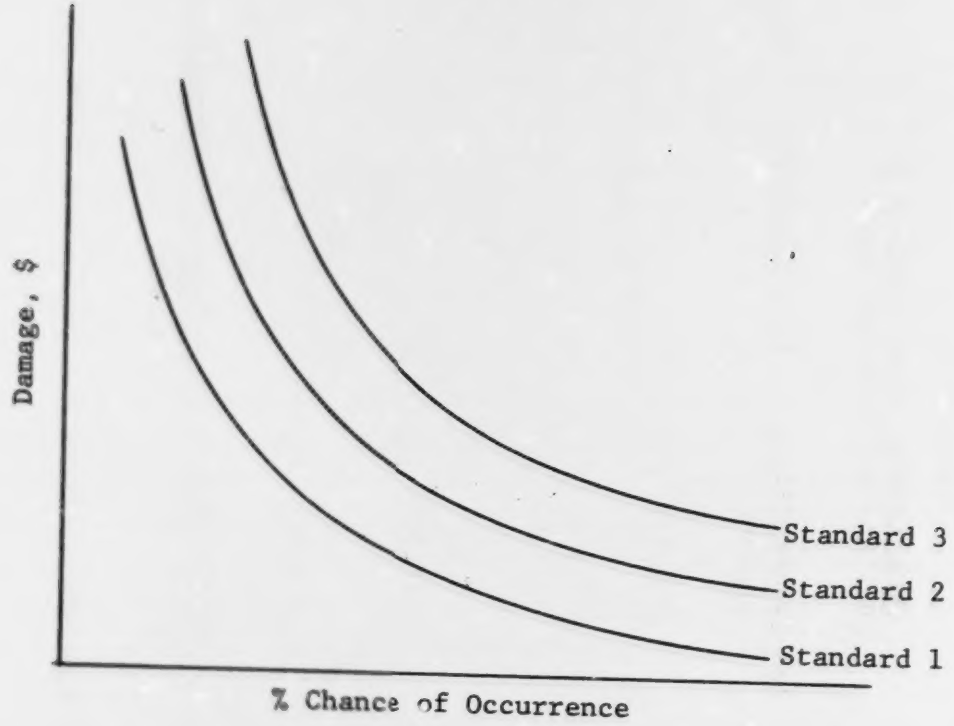

Figure 5-2

PROBABILITY-DAMAGE CURVES

impacted water quality segments. For each standard, there is an expected value of damage which can be expressed as shown in equation 1:

$$\mu = \int_{-\infty}^{\infty} xf(x)dx \qquad (1)$$

where f is the probability function and x a variable representing damage. The effect of each standard which is more stringent is a shift in the probability curve or an incremental reduction in probable damage. Therefore, the final estimation of the damages expected will be the area under the curves shown in Figure 5-2, and the benefits are the incremental curve areas. In Figure 5-3, the benefits obtained by utilizing more stringent standards are compared to the treatment costs as a final step in the analysis.

5.5.2.2 Measurement of Benefits

For each alternative standard, the impacted water quality segments were identified in Tables 5-3, 5-4, and 5-5. Utilizing the recreational value per stream mile, which was presented in Table 5-10, the total damage costs of each proposed regulation can be determined. These recreational losses are considered annual water quality damages which when combined with the probability of occurrence represent the expected damages of the effluent standard. To calculate the incremental benefits, the difference in areas between two damage curves (as shown in Figure 5-2) was calculated.

In Table 5-11, the annual expected damages associated with each of the five proposed standards are summarized. Although the Fox River is the highest quality waterway considered, the greatest damage costs are associated with the Chicago-Illinois River system at $114,000 per year. In all cases, the 0.2 mg/ℓ total cyanide maximum standard was associated with lower river damages than the 0.1 mg/ℓ total cyanide monthly average. Existing damages incurred varied from $70,000 on the Fox River

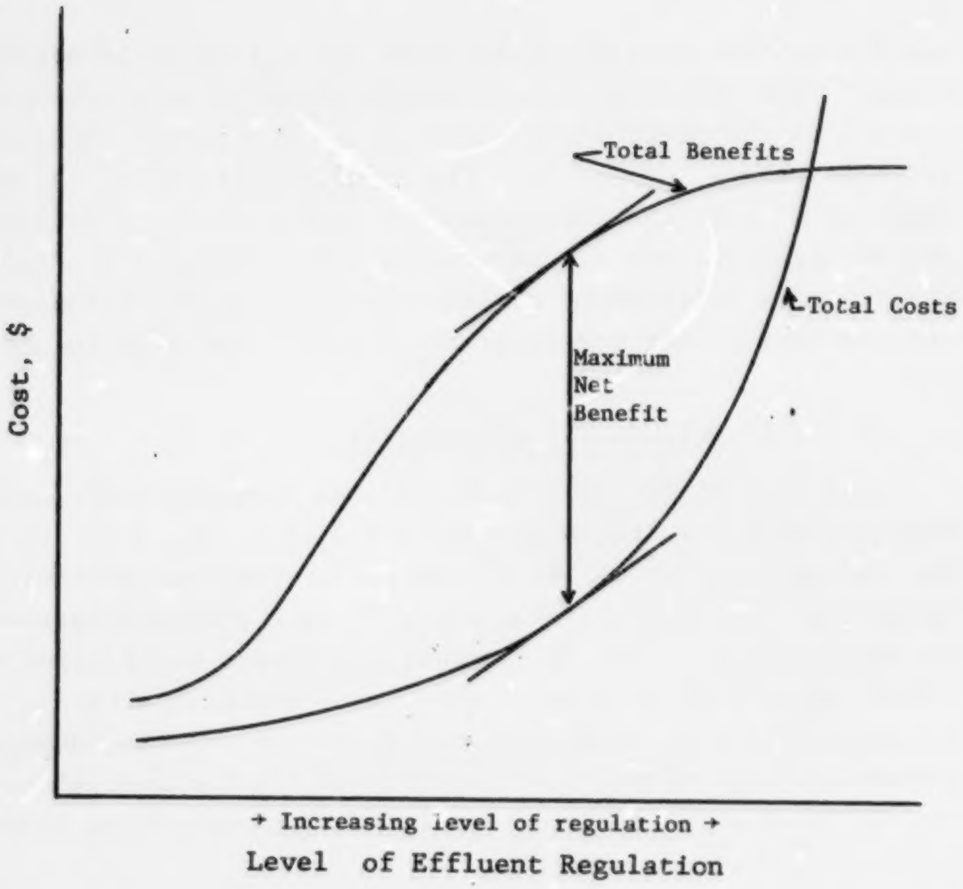

Figure 5-3

ESTIMATION OF TOTAL COSTS AND BENEFITS

Table 5-11

EXPECTED DAMAGES OF EFFLUENT STANDARDS

Effluent Standard (mg/ℓ total cyanide)	Expected Annual Damages ($)		
	Fox River	Chicago-Illinois River	Calumet River-Cal-Sag Channel
Existing Conditions	$70,000	$114,000	$80,000
0.025 -- 24-hr maximum	0	0	0
0.025 -- monthly avg.	0	28,750	2,000
0.05 -- monthly avg.	26,000	45,000	11,000
0.10 -- monthly avg.	70,000	114,000	80,000
0.20 -- 24-hr maximum	10,000	45,000	36,000

to $114,000 on the Chicago-Illinois River system. Thus, the implementation of four out of five standards resulted in the reduction in damages or net benefits to water quality.

To summarize the incremental benefits gained over unregulated conditions, Table 5-12 was prepared. The values in this table only depict the improvement over the unregulated situation, but do provide an indirect comparison of the standards themselves. The significance of these incremental benefits can only be properly evaluated by considering the associated costs. Therefore, until the costs are presented in Section 5.6, the complete evaluation of these must be postponed.

5.6 Costs of Regulation

To determine a cost effective effluent standard requires the estimation of treatment costs for each standard. The five effluent standards which were utilized to determine water quality changes now serve as design criteria for treatment facilities. For each major discharge segment, the costs of treatment are calculated. These costs are presented only for the purpose of approximating the cost of regulation, with an accuracy of ±100% for each individual discharger and an accuracy of ±40% for each group of dischargers (refineries, platers, etc.).

5.6.1 Method of Cyanide Treatment

While several witnesses testified at the R74-15, R74-16 Regulatory Hearings on a cyanide regulation change that the technology does not exist to achieve 0.025 mg/ℓ total cyanide, implied in these statements was that there exists no "economically viable" control method. Every control method that is capable of reducing cyanide to low levels (0.025-1.0 mg/ℓ) is either very capital intensive or energy intensive, and thus expensive. The methods considered in this study are briefly described below.

5.6.1.1 Alkaline Chlorination

Alkaline chlorination is perhaps the most common method for removing simple cyanide from both plating and steel mill

Table 5-12

ANNUAL BENEFITS OF PROPOSED EFFLUENT STANDARDS

Effluent Standard (mg/ℓ total cyanide)	Incremental Benefits Over Unregulated Conditions*		
	Fox River	Chicago-Illinois River	Calumet River-Cal Sag Channel
Total Recreational Value of Stream	$1,500,000	$670,000	$92,000
0.025 -- 24-hr maximum	1,500,000	670,000	92,000
0.025 -- monthly avg.	1,500,000	641,000	90,000
0.050 -- monthly avg.	1,474,000	625,000	81,000
0.10 -- monthly avg.	1,430,000	556,000	12,000
0.20 -- 24-hr maximum	1,490,000	625,000	44,000
Existing Conditions	1,430,000	556,000	12,000

* Unregulated conditions assumes complete annual fish kill.

waste streams. For the iron cyanides, however, alkaline chlorination is not a viable treatment method. Because this technique is utilized by nearly all cyanide users who discharge to municipal treatment plants (platers, heat treaters, etc.), it was considered "base level" treatment, required independently of whatever effluent cyanide standard is adopted. Thus, treatment costs were not assigned to any of the sewer dischargers who had to install "base level" treatment. Only costs beyond this base level were developed and utilized in this study.

5.6.1.2 Ozonation

Ozone, like chlorine, has been used to destroy simple cyanides. The complex cyanides, including ferro- and ferricyanide, can also be destroyed by ozonation[18]; however, the reaction rate between the iron cyanides and ozone is slower than with the simple cyanides, thus longer contact times and more ozone are required. The technology for designing ozonation systems for cyanide destruction is readily available. Ozone in conjunction with ultraviolet (U.V.) radiation is a more economical means for destroying complex cyanides, and thus ozone alone was not utilized in the cost estimating.

5.6.1.3 Ozone and U.V. Light

The use of U.V. lamps in conjunction with ozonation has been shown to increase the reaction rate between ozone and cyanides by over tenfold[18], including the iron cyanides. Although the mechanism is not fully understood, the formation of free radical oxygen atoms, which are much more reactive than ozone, is believed to occur.

Test results reported by Mobil Oil[19] in their bimonthly variance reports, using ozone plus U.V., showed that cyanide could be reduced to levels that would bring the entire refinery waste stream below 0.025 mg/ℓ total cyanide. Thus, ozone plus U.V. has been demonstrated on actual cyanide waste streams to be capable of achieving low levels of cyanide.

5.6.1.4 Biological Oxidation

Dr. James Irvin[6] summarized the literature regarding cyanide removal across biological treatment systems. According to Irvin, removals greater than 90% have been achieved and even for the iron cyanides removals from 20-70% were reported by biological means. Other evidence of biological removals was contained in Chapter 4, where the removal of cyanide as it traveled downstream in Illinois waterways was found to be significant. Granite City Steel utilizes oxidation ponds apparently with successful removal of cyanides. Thus, by isolating the in-plant cyanide stream and building a large storage tank (> 5 days holding time) with aeration, cyanide removals were assumed to follow the first order decay equation:

$$L_t = L_o e^{-0.12t}$$

where

L_t = cyanide concentration at time t

L_o = inlet cyanide concentration

t = time in days

The biological activity in a waste stream should be greater than found in the receiving stream, and thus the above equation is expected to be conservative.

5.6.1.5 Equalization and Storage

Through the use of equalization tanks, cyanide treatment efficiencies can be improved. This type of treatment is applicable to all of the industries with cyanide-bearing wastes, and especially for the plating industry where cyanide spills cannot be adequately treated without equalization. Equalization is also necessary for daily maximum standards (24-hr composites, not to be exceeded). Without equalization, the skewed distributions common for most cyanide dischargers (described in Chapter 3) cannot be brought into compliance.

Storage facilities will also be required for many industrial plants for achieving the standards during periods of malfunctions and breakdowns. This also is especially true of when daily maximum standards are imposed.

5.6.2 Treatment Methods by Industry

In this section, the treatment methods utilized by each industry to achieve the five different standards are described. The methods described below are designed to assure compliance with each standard at all times. A plant that violates the existing 0.025 mg/ℓ total cyanide standard only one day a month was considered currently out of compliance, and thus corrective action is required.

5.6.2.1 Petroleum Refineries

As described in Chapter 3, all eight of the refineries that discharge to Illinois waterways have violated the existing 0.025 mg/ℓ daily maximum during the last eighteen months. To attain such a level in their effluent will require varying degrees of treatment for the refineries. Clark and American can probably achieve compliance with the existing standard by in-plant monitoring, especially the sour water stripping processing rate after any shutdown of the stripper. Union Oil, with their water quench system, would be capable of meeting the existing standard by installing a storage tank for the stripped sour water stream during periods when the quench system is out-of-service. The two Texaco refineries will be required to install biological oxidation tanks for their stripped sour water streams to continuously achieve 0.025 mg/ℓ in their effluent. The remaining three refineries, Mobil, Marathon, and Shell would have to isolate the sour water from the FCC and construct a separate sour water stripper, with recycle for this waste stream. A bleed stream of 50 gpm from the new stripper will be treated with ozone and U.V. (Incineration of this 50 gpm bleed stream was also investigated, but was found to be more expensive than the ozone and U.V. system.)

If the standard is changed to a 0.025 mg/ℓ monthly average for total cyanide, four of the eight refineries are currently in compliance. Union Oil would still require the storage plus water quench, and Mobil, Marathon, and Shell would utilize an in-plant ozone-U.V. system.

A 0.050 mg/ℓ total cyanide monthly average standard would result in additional cyanide treatment facilities for the three following refineries:

Union -- Water Quench plus Storage

Mobil -- In-Plant Ozone plus U.V.

Marathon -- Biological Oxidation of In-Plant Stream

Shell -- No capital investment, but would require active monitoring

For a 0.100 mg/ℓ monthly average total cyanide, Union would utilize their existing water quench system, while Mobil Oil would install a biological oxidation tank for the stripped sour water waste stream.

If a 0.200 mg/ℓ total cyanide or 0.100 mg/ℓ simple cyanide (daily maximum) were adopted, Union would require a storage tank in addition to their existing water quench system and a biological oxidation tank would be designed for Mobil.

A summary of the number of refineries requiring capital expenditures to comply with each standard is presented below:

Total Cyanide Standard, mg/ℓ	Number of Refineries Requiring Additional Treatment
0.025 -- 24-hr maximum	8
0.025 -- monthly average	4
0.050 -- monthly average	3
0.100 -- monthly average	1
0.200 -- 24-hr maximum	2

5.6.2.2 Steel Industry

The Calumet STP of MSDGC receives the major cyanide-bearing waste streams from the steel industry in the state. Only Wisconsin Steel's blast furnace waste and Granite City Steel will continue to discharge directly to Illinois waterways. Granite City Steel discharges an average of 0.025 mg/ℓ total cyanide and, with an active in-plant cyanide monitoring program, could achieve the existing 0.025 mg/ℓ daily maximum standard.

For Wisconsin Steel's blast furnace the following treatment schemes were utilized for estimating compliance costs:

Total Cyanide Standard, mg/ℓ	Method of Compliance
0.025 -- 24-hr maximum	Recycle, equalization, ozone & U.V.
0.025 -- monthly average	Recycle, ozone & U.V.
0.050 -- monthly average	Recycle, ozone & U.V.
0.100 -- monthly average	Recycle
0.200 -- 24-hr maximum	Equalization

The cost of recycling the blast furnace water was not included in this cost estimate, since this was assumed to be "base level" treatment, independent of any cyanide standard.

The cost for the other steel mill waste streams are based on the level of treatment required to bring the Calumet STP into compliance. For the existing 0.025 mg/ℓ total cyanide daily maximum standard, ozone plus U.V. light and storage would be required for the following:

Wisconsin Steel -- Coke Plant
Interlake Steel -- Blast Furnace
Interlake Steel -- Coke Plant
Republic Steel -- Coke Plant

The only facilities added for Republic's blast furnace waste stream would be storage facilities.

If the standard were changed to a 0.025 mg/ℓ monthly average, ozone plus U.V. would still be required, but without the storage facilities for the four sites listed above. At the 0.050 mg/ℓ monthly average standard, ozone plus U.V. would be required on the coke plant waste streams of Wisconsin Steel, Interlake, and Republic.

The Calumet STP would be in compliance with a 0.1 mg/ℓ monthly average or a 0.200 mg/ℓ daily maximum total cyanide standard. Thus, no additional cost would be required by these steel companies.

5.6.2.3 Plating Industry -- Direct Dischargers

In Chapter 3, five plating companies were identified as direct dischargers to Illinois waterways. Very little data is available on these five firms, but regardless of the cyanide standard adopted, additional treatment will be required. These platers probably already utilize alkaline chlorination, but cyanide levels in the 0.025-0.1 mg/ℓ range are not achievable with alkaline chlorination. Thus, ozone plus U.V. was utilized to estimate the cost based on an assumed flow rate of 50,000 gallons per day for each firm. Equalization was also included in each cost estimate except for the 0.100 mg/ℓ monthly average, where just ozone plus U.V. was utilized.

5.6.2.4 Industrial Dischargers to Municipal Sewers

In Chapter 3, 31 municipalities were included as dischargers violating the existing cyanide standard. It was assumed that the municipalities violating the standard would go back to the industrial cyanide dischargers in their district and force them to install additional treatment facilities. The "typical" industrial discharger was assumed to discharge 50,000-100,000 gpd to the sewer, and cyanide levels between 1 and 3 mg/ℓ total cyanide.

Many of the municipalities are small communities with flows less than 1 MGD. Twelve of these communities currently discharge an average cyanide level less than 0.025 mg/ℓ, and thus installation of equalization facilities by their industrial cyanide discharger would bring them into compliance with the existing standard. For the municipalities with higher cyanide levels, ozone plus U.V. and/or equalization was utilized for estimating the compliance costs.

For the MSDGC-WSW plant, 91 cyanide users have been identified[7]. For cost estimating purposes, it was assumed that each of the 91 industries discharges 100,000 gpd and an average of 4 mg/ℓ total cyanide. While some of the 91 dischargers are currently violating MSDGC's 10 mg/ℓ total cyanide level, these were considered brought into compliance as "base level" treatment independent of the cyanide standard adopted. For the WSW plant to achieve compliance with the existing standard, equalization would be required at all 91 plants to improve the existing cyanide treatment facilities. Because of the large number of cyanide dischargers, equalization at all plants was also necessary to achieve the 0 025 mg/ℓ monthly average standard. Compliance with the 0.050 mg/ℓ monthly average and the 0.200 mg/ℓ daily maximum standards can be achieved by careful monitoring of the cyanide dischargers once all 91 industrial plants are brought into compliance with the existing sewer ordinance. The WSW plant currently achieves the 0.100 mg/ℓ monthly average standard, and thus no additional costs were associated with this standard.

5.6.3 Cost of Compliance by River Basin

Water quality problems associated with cyanide appear to be limited to three river basins in the State of Illinois. Future industrial growth in Illinois or a relaxation in the cyanide effluent standard could, of course, increase water quality problems in future years. The treatment costs presented in this section are based on the existing situation in each basin and do not take any future industrial growth into consideration.

5.6.3.1 Fox River Basin

Five municipal treatment plants along the Fox River currently violate the existing Illinois cyanide effluent standard.

Table 5-13 presents the estimated capital and annual treatment costs for compliance with the five alternate standards. (The annual cost includes the amortized capital investment and is a measure of the actual total cost on a yearly basis.)

As can be seen in Table 5-13, the total capital investment on the Fox River drops from $1,690,000 for compliance of the existing standard to $70,000 for a 0.100 mg/ℓ monthly average total cyanide standard. Standards based on 0.2 mg/ℓ total cyanide (and 0.1 mg/ℓ simple cyanide), not to be exceeded based on 24-hr samples, would require equalization facilities at 7 industrial plants in three cities, plus an active cyanide monitoring program at each plant. A monthly average standard of 0.1 mg/ℓ total cyanide only necessitates an equalization facility for one industrial plant.

5.6.3.2 Calumet River-Cal Sag Channel

When all of the steel mills on the Calumet River have completed the routing of their cyanide effluents to MSDGC's Calumet plant, there will only be two cyanide dischargers on this waterway, Wisconsin Steel's blast furnace and MSDGC's Calumet plant. Table 5-14 summarizes the requirements for Wisconson Steel's blast furnace and the steel companies discharging to the Calumet STP.

The blast furnace waste will require recycling for four of the standards being evaluated, although as discussed earlier, recycling was considered "base level" treatment, and thus no cost was assigned for this. The total capital investment to bring these two dischargers into compliance range from $8,890,000 for the existing standard to $0 for a 0.1 mg/ℓ total cyanide monthly average standard. Compliance with the 0.2 mg/ℓ total cyanide standard (and 0.1 mg/ℓ simple cyanide) daily maximum standard will require Wisconsin Steel to install an equalization basin prior to their alkaline chlorination system.

Table 5-13

COST ESTIMATATION OF COMPLIANCE ON THL FOX RIVER

Municipality	Estimated Number of Industrial Cyanide Dischargers	0.025 mg/ℓ Total CN⁻ Daily Maximum			0.025 mg/ℓ Total CN⁻ Monthly Average			0.05 mg/ℓ Total CN⁻ Monthly Average			0.1 mg/ℓ Total CN⁻ Monthly Average			0.2 mg/ℓ Total CN⁻ Daily Maximum		
		Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)
Fox River Grove	1	Ozone & U.V. and equalization	113,000	25,000	Ozone & U.V.	43,000	10,000	None	0	0	None	0	0	None	0	0
East Dundee	1	Equalization	70,000	20,000	None	0	0	None	0	0	None	0	0	None	0	0
West Dundee	1	Ozone & U.V. and equalization	138,000	29,000	Ozone & U.V. and equalization	113,000	20,000	Ozone & U.V.	43,000	10,000	None	0	0	Equalization	70,000	15,000
Elgin	4	Ozone & U.V.	616,000	105,000	Ozone & U.V.	487,000	75,000	Equalization	361,000	48,000	Equalization (largest plant only)	70,000	10,000	Equalization (all 4 plants)	361,000	48,000
Aurora	2	Ozone & U.V. and equalization	754,000	122,000	Ozone & U.V.	342,000	68,000	Equalization	432,000	56,000	None	0	0	Equalization	432,000	66,000
		Total Cost	1,690,000	301,000		985,000	173,000		836,000	114,000		70,000	10,000		863,000	129,000

Table 5-14

COST ESTIMATION OF COMPLIANCE ON THE CALUMET RIVER-CAL SAG CHANNEL

Discharger	0.025 mg/ Total CN^- Daily Maximum			0.025 mg/ Total CN^- Monthly Average			0.05 mg/ℓ Total CN^- Monthly Average			0.1 mg/ Total CN^- Monthly Average			0.2 mg/ Total CN^- Daily Maximum		
	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)
Wisconsin Steel -- blast furnace	Recycle, ozone & U.V. and equalization	1,490,000	400,000	Recycle and ozone & U.V.	1,000,000	350,000	Recycle and ozone & U.V.	550,000	140,000	Recycle	0	0	Equalization	315,000	32,000
MSDGC Calumet Plant	Ozone & U.V. and equalization of coke plant and blast furnace wastes	7,400,000	2,700,000	Ozone & U.V. on coke plant and blast furnace wastes	4,700,000	2,400,000	Ozone & U.V. on coke plant wastes	2,900,000	1,400,000	No additional treatment	0	0	No additional treatment	0	0
	Total Cost	8,890,000	3,100,000		5,700,000	2,750,000		3,450,000	1,540,000		0	0		315,000	32,000

5.6.3.3 Chicago-Illinois River System

Three municipal treatment plants plus three refineries discharge cyanide in excess of the current standard. Table 5-15 summarizes the cost to bring each of these dischargers into compliance with each of the five alternative standards. The capital costs range from \$9,650,000 for compliance with the existing standard to \$1,060,000 for the 0.100 mg/ℓ total cyanide monthly average standard.

5.6.4 Cost by Industry

Four major industrial sectors were identified in this study as violating the existing cyanide effluent standard:

Petroleum refineries

Iron and steel industry

Direct discharge plating companies

Industries discharging to municipal treatment plants

The capital investment requirements for each sector are summarized in Table 5-16. The total capital investment for the industry in the State of Illinois to comply with the existing cyanide regulation is estimated at \$27,500,000. If the existing regulation were modified from a daily maximum to a monthly average, the total cost would drop to \$21,000,000. A standard of 0.100 mg/ℓ total cyanide, based on a monthly average would require a total capital investment in the state of \$1,510,000; of which \$1,000,000 would be spent by Mobil Oil.

The annual cost requirements (including the amortized capital investments) for each industry sector are summarized in Table 5-17. The annual costs range from \$5,680,000 for compliance with the existing standard to \$230,000 for compliance with the 0.100 mg/ℓ monthly average total cyanide standard.

For each industrial sector, the cost of compliance with the 0.1 mg/ℓ monthly average standard is more economical then the 0.2 mg/ℓ daily standard. This can be explained by the wide

Table 5-15

COST ESTIMATION OF COMPLIANCE ON THE CHICAGO-ILLINOIS RIVER SYSTEM

	0.025 mg/ℓ Total CN^- Daily Maximum			0.025 mg/ℓ Total CN^- Monthly Average			0.05 mg/ℓ Total CN^- Monthly Average			0.10 mg/ℓ Total CN^- Monthly Average			0.20 mg/ℓ Total CN^- Daily Maximum		
Discharger	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method of Compliance	Capital Investment ($)	Annual Cost ($)	Method Compliance	Capital Investment ($)	Annual Cost ($)
MSDGC Northside Plant	Monitoring	0	50,000	--	0	0	--	0	0	--	0	0	--	0	0
MSDGC West-Southwest Plant	Equalization at 91 plants and monitoring	6,500,000	710,000	Equalization at 91 plants and monitoring	6,500,000	710,000	Monitoring	0	50,000	--	0	0	Monitoring	0	50,000
Union Oil	Incineration and storage	500,000	60,000	Incineration and storage	370,000	50,000	Incineration and storage	190,000	30,000	Incineration	60,000	10,000	Incineration and storage	250,000	30,000
Texaco (Lockport)	Storage and monitoring	50,000	30,000	--	0	0	--	0	0	--	0	0	--	0	0
Joliet STP	Equalization and monitoring	900,000	110,000	Equalization and monitoring	580,000	70,000	--	0	0	--	0	0	--	0	0
Mobil Oil	Ozone & U.V.	1,700,000	270,000	Ozone & U.V.	1,700,000	270,000	Ozone & U.V.	1,300,000	230,000	11-day retention pond	1,000,000	130,000	11-day retention pond	1,000,000	130,000
	Total Cost	9,650,000	1,230,000		9,150,000	1,100,000		1,490,000	310,000		1,060,000	140,000		1,250,000	210,000

Table 5-16

CAPITAL INVESTMENT REQUIREMENTS FOR COMPLIANCE WITH VARIOUS STANDARDS

Effluent Standard (mg/ℓ cyanide)	Capital Investment of Industry				Total
	Petroleum Refineries	Iron and Steel	Direct Discharge Platers	Industries Discharging to Municipal Treatment Plants*	
0.025 -- 24-hr maximum	$5,620,000	$8,890,000	$1,320,000	$11,650,000	$27,500,000
0.025 -- monthly average	5,020,000	5,700,000	880,000	9,420,000	21,000,000
0.05 -- monthly average	2,100,000	3,450,000	680,000	1,480,000	7,700,000
0.100 -- monthly average	1,060,000	0	220,000	230,000	1,510,000
0.20 -- 24-hr maximum	1,250,000	320,000	560,000	1,100,000	3,230,000

* Excludes MSDGC's Calumet plant, which is included in the "Iron and Steel" industry category.

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Table 5-17

TOTAL ANNUAL COST REQUIREMENTS
FOR COMPLIANCE WITH VARIOUS STANDARDS

Effluent Standard, mg/ℓ total cyanide	Annual Cost by Industry, $				Total
	Petroleum Refineries	Iron and Steel	Direct Discharge Platers	Industries Discharging to Municipal STP's*	
0.025 -- 24-hr maximum	860,000	3,100,000	230,000	1,490,000	$5,680,000
0.025 -- monthly average	730,000	2,750,000	150,000	1,120,000	4,750,000
0.050 -- monthly average	350,000	1,540,000	120,000	240,000	2,250,000
0.100 -- monthly average	150,000	0	50,000	30,000	230,000
0.200 -- 24-hr maximum	170,000	0	100,000	210,000	480,000

* Excludes MSDGC's Calumet plant, which is included in the "Iron and Steel" industry.

fluctuation in the effluent cyanide level from all of the dischargers as shown graphically in Chapter 3. The cost of preventing the peak cyanide discharges is greater because large equalization units and spare equipment for malfunctions and breakdowns must be included for compliance.

Chapter 6

DETERMINATION OF OPTIMAL EFFLUENT STANDARDS

6.1 Introduction

The criteria for selecting an effluent standard are not only water quality considerations but also economic and administrative factors. A benefit-cost analysis is an indicator of the economic allocation of resources which is optimal. However, real world constraints on data and measurement of benefits have hindered the use of this tool. Other factors of concern are enforcement feasibility, administrative requirements of implementation, impact of promulgation, and future industrial growth. Although it is difficult to quantify these factors, an awareness of their importance enhances the general decision-making process.

An effluent standard is designed to protect and maintain the quality of the waterways. However, the ability to accomplish this relies on strict enforcement of the law to achieve compliance. It is important, therefore, that the regulation is precisely defined in legal and technical terms. The precision of the analytical test method utilized in monitoring the pollutant must also be considered in the establishment of standards.

The regulation which is established should be readily incorporated into the existing structure of standards. Any special requirements for the governmental agency or discharger to implement a standard raises the overall cost and restricts the ease of compliance. The use of additional inspectors, laboratory facilities, expanded bureaucracy, or reporting forms augments the cost of regulation and must be considered.

The impact of the total costs of regulation upon industry must be evaluated in the final selection of a standard. Disruption in the supply of materials, price raises, and increased unemployment are potential results of promulgation. Business closures or the curtailment of industrial growth certainly would

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cause such phenomena and must be analyzed. The cost-benefit analysis presented herein provides an indication as to the possibility of such effects, but does not fully analyze them.

In evaluating the costs and benefits of regulation, a range of possible effluent cyanide standards was considered. This range was determined by examining the merits and deficiencies of effluent levels with regard to enforcement feasibility, environmental consequences, and needs of the dischargers of cyanide. Once the effluent standard scope was ascertained, the costs and benefits of various values were calculated. In the analysis of these results, the data constraints must be regarded as limiting factors; however, an indication of the appropriate level of regulation can be determined.

6.2 Alternative Effluent Standards

Modifications to the existing effluent cyanide standard have been proposed by two groups of dischargers. From Chapters 3 and 5, it is apparent that the number of industries and municipalities affected by the cyanide standard far exceeds the two groups of petitioners. In determining the effluent standards to be evaluated according to costs and benefits, there are several aspects of this problem to be considered, including:

Analytical problems

Existing cyanide levels in effluents

Form of cyanide in effluents and rivers

Toxicity of various forms of cyanide

The first factor to be considered is analytical limitations. The present analytical methods (U.S. EPA, Standard Methods, and ASTM) have standard deviations greater than 100% at the 0.025 mg/ℓ concentration of total cyanide. Thus, the present effluent standard, which is based on a "not-to-be-exceeded" 24-hr composite sample, results in violations simply due to analytical fluctuations. Most dischargers who periodically violate the 0.025 mg/ℓ standard have not approached the Pollution Control Board for a variance, primarily because they are uncertain whether they are indeed in violation of the Illinois law. The Control Board should consider the analytical variability of all trace pollutants and clearly establish the definition of a violation. An example of this analytical problem with respect to cyanide was discussed in the municipal discharge section of Chapter 3. Fourteen of the 31 municipalities identified as violating the existing cyanide standard had only one sample greater than 0.025 mg/ℓ total cyanide, which, at least for the majority of these municipalities, can be attributed to the precision of the analytical test procedure. Using a strict interpretation, these municipalities were in violation of the law because of the one analysis greater than 0.025 mg/ℓ.

The second factor of importance in formulating effluent standards is the existing levels of cyanide discharged to receiving streams. In all the data collected in Chapter 3, only one discharger, Modern Plating, at any time exceeded 1.0 mg/ℓ total cyanide. Thus, the need for a 1.0 or 2.0 mg/ℓ total cyanide standard is dubious, and the uncertainty regarding the innocuous characteristics does not warrant such high levels. In Chapter 3, the wide variability in cyanide levels discharged was also shown for all dischargers. The ability for industry to control the variability is expensive, requiring large equalization facilities plus duplicate control equipment for any malfunction or breakdown. Therefore, daily maximum standards would probably be more expensive than monthly averages.

The limited data available on cyanide forms, which is the third factor for consideration, indicates that approximately 50% of the cyanide in most effluents is detected by the simple cyanide test procedure. Based on this, a total cyanide standard of 1.0 or 2.0 mg/ℓ would be the equivalent of no total cyanide standard at all since a simple cyanide standard of 0.1 mg/ℓ would become the limiting parameter. All dischargers would then monitor simple cyanide instead of total cyanide. While the total cyanide test procedures still require refinement, the simple cyanide procedures are less advanced.

Toxicity must always be considered when evaluating effluent standards. The information regarding cyanide indicates that hydrocyanic acid or HCN is the most toxic form. Concentrations of HCN greater than 0.025 mg/ℓ have significant chronic affects on fish according to Broderius[17]. While the form of cyanide in Illinois waterways is not known at this time, it seems plausible that if the effluents contain 50% simple cyanide, this form of cyanide in the waterways could also approach 50%. (Limited data presented by MSDGC[7], indicates the simple cyanide, may be well below the 50% level, but considerably more data is needed to confirm their findings.) At the pH levels found in Illinois waterways, a large fraction of the simple cyanide would be expected to be in the HCN form, and, thus, effluent limits should be fixed to minimize the possibility of damage.

Based on the above aspects, monthly average standards represent a feasible approach to cyanide effluent standards. Monthly averages would eliminate the question of compliance due to the analytical precision of a single sample. Monthly averages would also allow fluctuation in effluent cyanide levels currently experienced by the dischargers.

Total cyanide standards of 1 or 2 mg/ℓ are not warranted, since the fate of the complex cyanides in the receiving stream is not well understood. If most of the discharges contain approximately 50% simple cyanide, as the limited data suggests, a total cyanide standard of 0.2 mg/ℓ would be equivalent to the proposed 0.1 mg/ℓ simple cyanide standard proposed by the petitioners.

Five potential standards were selected for evaluation, based on the above discussion, as being feasible levels of compliance:

0.025 mg/ℓ -- daily maximum

0.025 mg/ℓ -- monthly average

0.050 mg/ℓ -- monthly average

0.100 mg/ℓ -- monthly average

0.200 mg/ℓ -- daily maximum

If a monthly average standard is ultimately adopted by the Pollution Control Board, an additional standard should also be adopted to limit the maximum discharge. This could be a statement similar to that included in the BOD and SS standards where,

> "...no more than 5% of the samples collected shall exceed 2.5 times the numerical limits..."

6.3 Benefit-Cost Analysis

6.3.1 Theoretical Underpinnings

In Chapter 5, the benefits and costs of five alternative effluent standards were determined. Analysis of these values from Tables 5-11, 5-13, 5-14, and 5-15 requires an understanding of the purposes and economic importance of a benefit-cost evaluation.

The benefits from public projects or activities are reflected by consumer's willingness to pay for such activities. In our particular case, the expense of a fishing trip is considered the price paid, and the number of trips which might be lost without regulation but are saved due to effluent standards are considered the benefits of regulation. The determination of the appropriate standard is not based on the ratio of benefits and costs but rather that of marginal benefits and costs. Figure 5-3 provided a picture of total benefit and cost curves. When the incremental dollar value of another unit of benefits equals that of treatment costs, the correct economic allocation of resources has occurred. This can be explained in a mathematical manner to demonstrate the reasonableness of such an approach.

If the net benefits of a project are defined as the gross benefits less the costs, then equation 1 represents this relationship[22].

$$W(A) = E(Y) - C(X) \tag{1}$$

where

W(A) = net benefits
C(X) = costs
E(Y) = gross benefits
X = input factors
Y = output factors

The gross benefits can be further defined as the area under the demand curve or as written in equation 2.

$$E(y) = \int_0^y D(\eta)\,d\eta \tag{2}$$

$D(\eta)$ = demand curve

To maximize the net benefits of a project, one differentiates equation 1, which defines the production function of benefits. The results are shown in equation 3.

$$D\frac{\partial y}{\partial x} = \frac{\partial c}{\partial x} \tag{3}$$

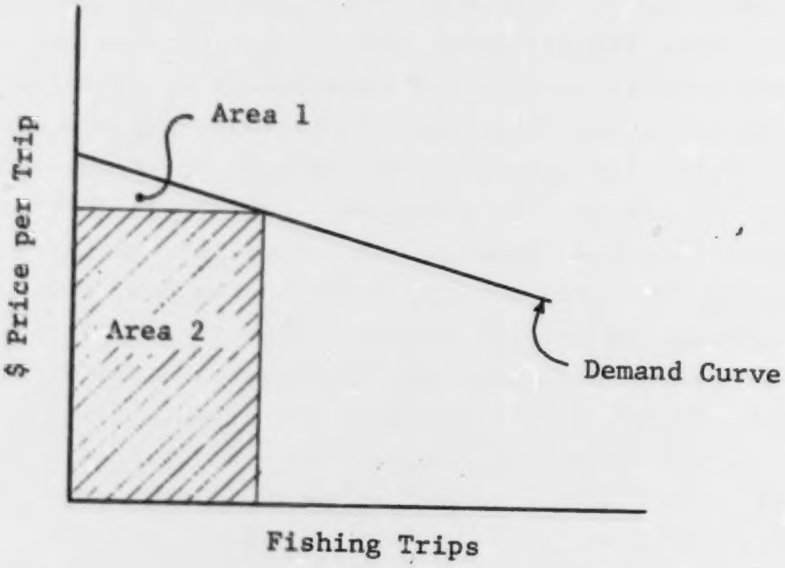
$\frac{\partial c}{\partial x}$ = marginal costs for net input unit
D = demand price for output (y)
$\frac{\partial y}{\partial x}$ = amount of y produced for next input unit (x)

Equation 3 thus states that the marginal costs are equal to the marginal benefit. In terms of a graph, the slopes of the benefit and cost curves are equal at the maximum benefit point.

In this particular analysis, there are two special points of consideration which deviate from the theoretical approach described. Benefits and costs are typically measured as the present value of an ensuing stream of values. This is often utilized because of variation in the annual and capital costs over time. In our analysis, the benefits and costs are annual values. This is considered appropriate because the annualized cost and benefit streams are constant to an infinite horizon, which is different from most recreational project evaluations. Another point for consideration relates to the benefit calculation. In theory, the area under the demand curve reflects the total benefits; however, this requires identification of the demand curve for fishing trips on the Fox, Illinois, Des Plaines, and Calumet Rivers. This is a very difficult task, and thus the market price for fishing trips was determined instead. Figure 6-1 illustrates the difference in values from not including the consumer surplus or Area 1 on the figures. This Area 1 is probably small because the distance traveled for fishing (less than 50 miles) is small. Typically, demand curves for recreational sites are based on distances traveled to utilize a site. Since 80% of all fishermen travel less than 50 miles, their demand curve is very elastic as shown in Figure 6-1. It must be noted, though, that because the consumer surplus (or Area 1) was not included, the benefits represent a conservative estimation in the economic sense of measurement.

6.3.2 Benefit-Cost Analysis of Fox River, Chicago-Illinois River System, and Calumet River-Cal Sag Channel

The total benefits and costs were calculated for five alternative regulations in Chapter 5. These values were analyzed for three river systems, the Fox, Chicago-Illinois,



Total Benefits = Area 1 + Area 2

Benefits measured in this program = Area 2

Figure 6-1

BENEFIT ESTIMATION

and Cal Sag-Calumet Rivers to provide an indication of an appropriate effluent standard. The measurement of marginal benefits and costs from these data provided the basis of Figures 6-2, 6-3, and 6-4 for the Fox River, Calumet River-Cal Sag Channel, and Chicago-Illinois River systems, respectively. The point of interest in these figures is the intersection of the marginal benefit and marginal cost curves. At this intersection, the two factors are equal, and, as discussed in Section 6.3.1, the maximum net benefits are realized. Thus, the effluent standard which represents the maximum net benefits is tabulated as follows from the graphs:

River Basin	Monthly Concentration Standard
Fox River	0.075 mg/ℓ total cyanide
Chicago-Illinois Rivers	0.09 mg/ℓ total cyanide
Calumet River-Cal Sag Channel	0.10 mg/ℓ total cyanide

A monthly standard of 0.075 mg/ℓ to 0.10 mg/ℓ total cyanide indicates the range of intersections obtained for these river systems. Even though the marginal cost and benefit values vary significantly from one river system to another, the range of standards is not great. This is due to the rapidly decreasing costs of compliance as the 0.10 mg/ℓ standard is reached.

The daily maximum standards of 0.025 mg/ℓ and 0.20 mg/ℓ were not evaluated in the same manner because the incremental benefits gained through a monthly standard were more efficient in the sense that a dollar spent on treatment yielded a greater benefit. This can be exemplified by examining the Fox River cost and benefit data shown below.

	0.025 mg/ℓ Monthly Average	0.025 mg/ℓ Daily Maximum
Annual Benefits	$1,500,000	$1,500,000
Annual Costs	173,000	301,000

Greater benefits are achieved for each dollar expended in complying with a monthly standard than a daily maximum. The

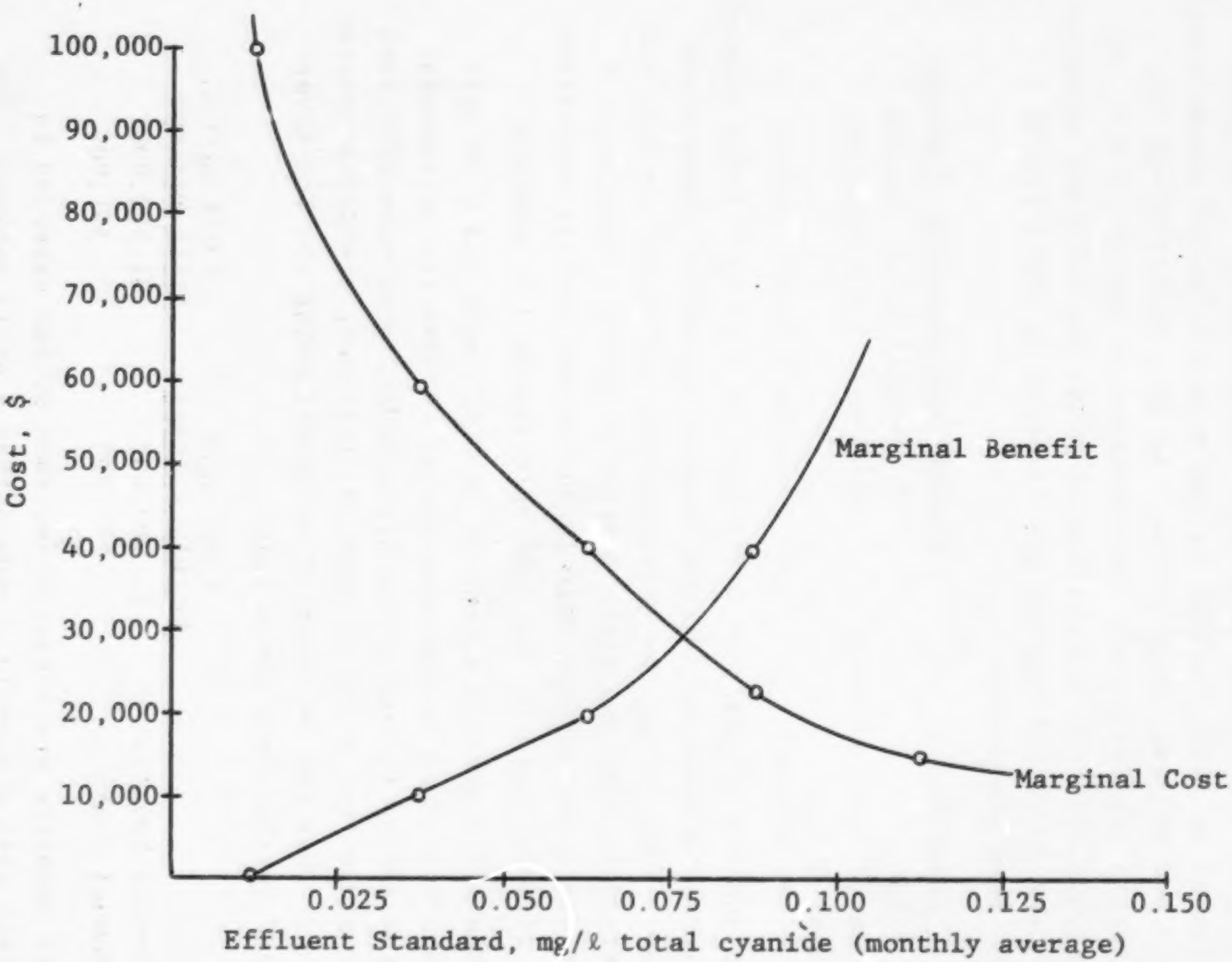


Figure 6-2

MARGINAL COST-BENEFIT CURVES FOR FOX RIVER

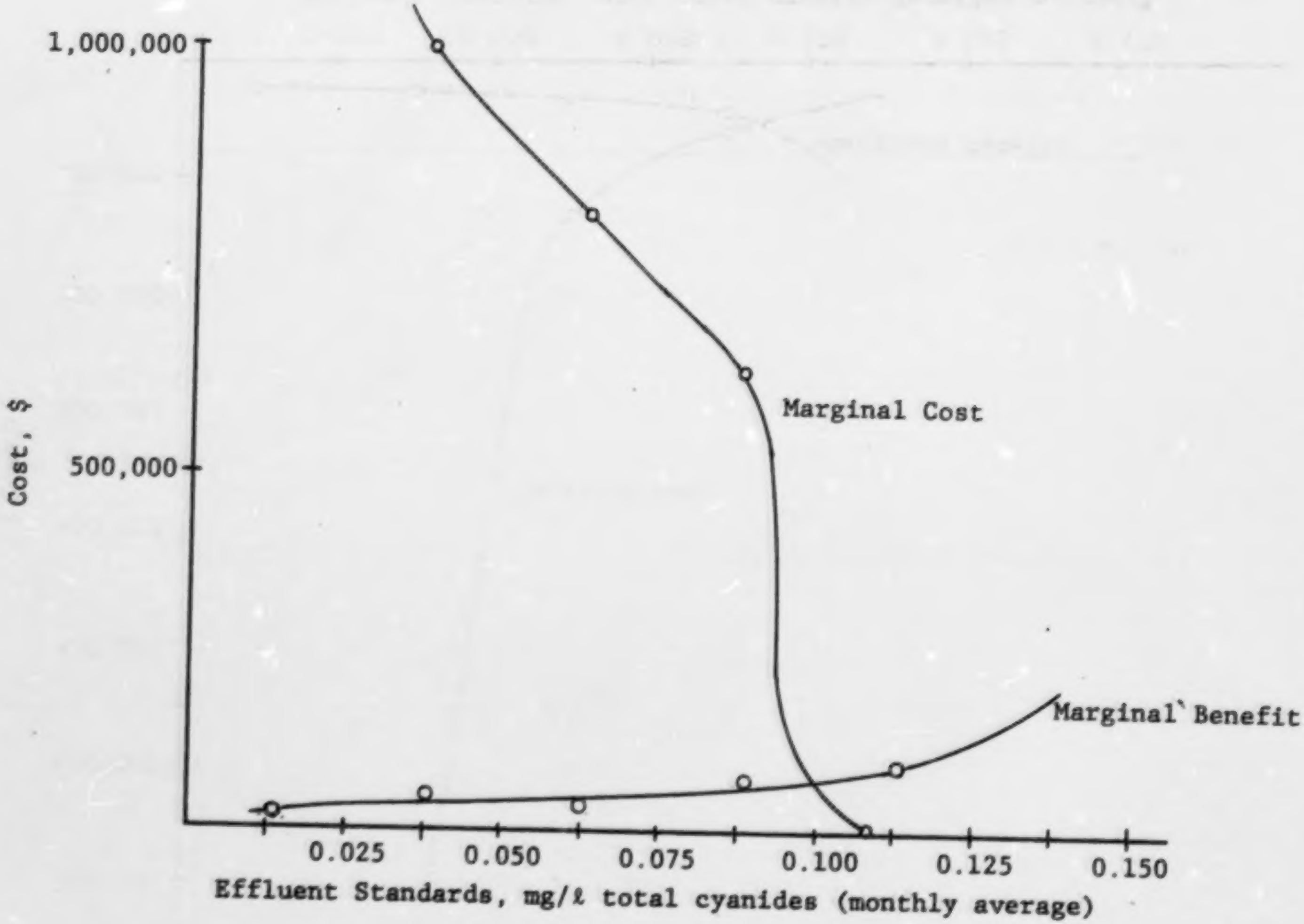


Figure 6-3

MARGINAL COST-BENEFIT CURVES FOR CALUMET RIVER-CAL SAG CHANNEL

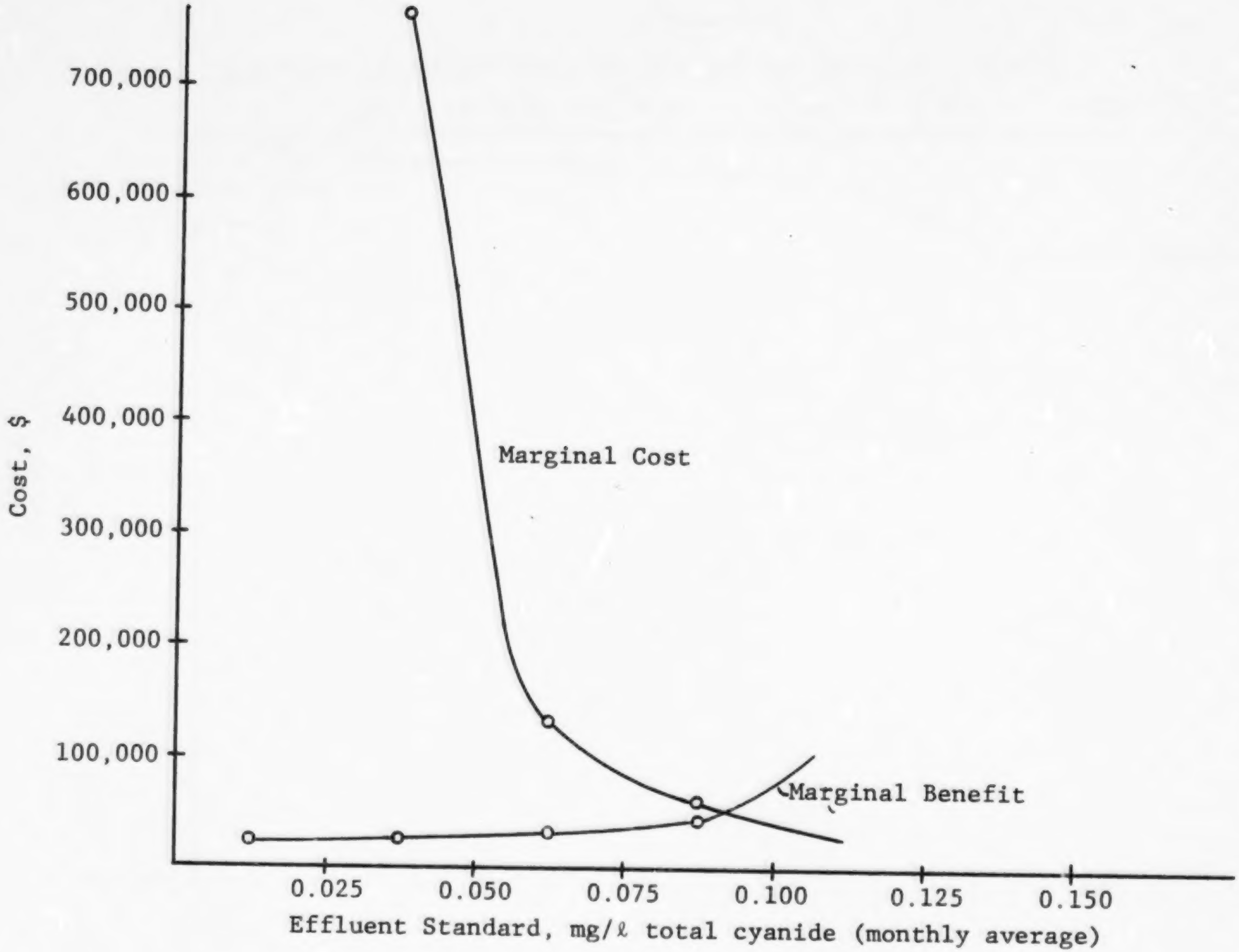


Figure 6-4

MARGINAL COST-BENEFIT CURVES FOR CHICAGO-ILLINOIS RIVER SYSTEM benefits for the Fox are the same for each standard, but costs are increased by 70%. Therefore, the monthly average standard appears to represent a more feasible solution to analytical and treatment requirements than the daily maximum regulation.

6.4 Overview of the Cyanide Problem

Utilizing the results of the benefit-cost analysis, the cyanide problem within the state is re-evaluated. The number of dischargers out of compliance and their treatment costs can be readily ascertained. In Table 6-1, a summary is provided of existing and revised conditions with a 0.1 mg/ℓ and 0.05 mg/ℓ total cyanide monthly average.

By modifying the existing standard to 0.05 mg/ℓ monthly average total cyanide, the number of violators is reduced from 70 to 21. The 26 miscellaneous dischargers represent a group which is readily in compliance with any but the present standard. The compliance costs presented exclude any treatment cost for this miscellaneous group since the status of their violation is questionable. The capital cost of compliance drops from $27,500,000 for the existing standard to $7,700,000 for a revised monthly average standard of 0.05 mg/ℓ total cyanide, and at 0.10 mg/ℓ only $1,500,000 is required for 10 dischargers out of compliance.

The plating firms which are direct dischargers cannot meet even a 0.10 mg/ℓ effluent limitation with their existing technology, and thus they represent a large portion of the treatment costs. Two refineries and three municipalities would also be required to have additional facilities for a 0.100 mg/ℓ monthly average standard. The number affected, however, is much smaller than for the existing standard.

Based upon the cost-benefit analysis and information on the three river basins examined, an effluent standard between 0.075 mg/ℓ and 0.10 mg/ℓ appears to be appropriate for these three basins. Benefits of regulation for isolated cyanide

Table 6-1

COMPARISON OF CYANIDE DISCHARGER PROBLEM FOR EXISTING AND REVISED STANDARD

	Existing Conditions	0.05 mg/ℓ CN^- Monthly Average	0.10 mg/ℓ CN^- Monthly Average
Number of Dischargers Out of Compliance			
municipalities	31	10	3
refineries	8	3	2
platers	5	5	5
steel	4	3	0
miscellaneous	26	0	0
Total Capital Cost of Compliance	$27,500,000	$7,700,000	$1,510,000
Annual Cost of Compliance	$ 5,680,000	$2,250,000	$ 230,000

dischargers on other streams may not be as significant as demonstrated for these three basins. Application of a uniform effluent standard across the state, however, does protect the receiving streams allowing for industrial growth in the future.

Chapter 7

LIMITS TO THE ANALYSIS

Because of the technical nature of the evaluation performed, it is appropriate to assemble the important assumptions which influenced the final values obtained. The limitations to the analysis are listed in three sections, as those which would result in a more restrictive standard, those in a less restrictive standard, and finally those which have an uncertain effect.

ASSUMPTIONS LEADING TO A MORE RESTRICTIVE STANDARD

1. The simple cyanide level in both the treated effluents and in the Illinois waterways was assumed to be 50% of the total cyanide present. Based on a very limited amount of data presented by MSDGC, the simple cyanide in the waterways may account for less than 50% of the total cyanide present. Also, the simple cyanide was presumed to result in toxic effects similar to hydrocyanic acid (HCN).

2. In estimating the costs of compliance, no costs were assumed for the defined base level treatment.

3. In estimating the potential damage costs in each river basin, the assumption was made that no alternate fishing sites are available to the local fishermen, and thus these fishermen would lose one year of river fishing.

ASSUMPTIONS LEADING TO A LESS RESTRICTIVE STANDARD

1. In estimating the recreational benefits, existing water quality conditions were utilized. As more advanced wastewater treatment plants are installed, water quality should improve and thus the recreational value will increase. By utilizing the existing water quality, the potential recreational value was underestimated.

2. The determination of cyanide loadings in the waterways was based on existing industrial dischargers with no allowance for growth. If projected cyanide dischargers are included in the analysis, a more stringent standard may be required.

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3. Strict interpretation of the standard was utilized as a design criteria for treatment facilities. The objective of each design and cost estimate was to prevent any violation of the effluent standard. If a more liberal approach is taken and periodic violations of the standard are permitted, the cost of compliance would be lower than presented in this report.

4. In evaluation of the recreational value of fishing, only the market value of the activity was calculated. Thus, the consumer surplus or willingness to pay for fishing was omitted, which reduced the estimated benefits.

5. In evaluation of the chronic and acute effects of cyanide, a loss of fishing for one year was assumed. A reduction in fish population, either through chronic or acute toxicity would probably require longer than one year to compensate and redevelop the normal fish population.

ASSUMPTIONS WITH UNCERTAIN EFFECTS

1. Concentrations of acute and chronic effects were determined as 0.1 mg/ℓ and 0.025 mg/ℓ simple cyanide. Depending upon the results of additional research, these may be considered over- or underprotective levels.

2. In evaluating the damage to streams caused by high cyanide concentrations, it was assumed that if chronic or acute levels were reached that the resulting damage was total loss of the river segment affected. This appeared viable since a fish kill or loss of reproduction would reduce fish populations and fishing activity would cease. There may be a time of exposure element which could change this assumption, but sufficient data are lacking.

3. In estimating costs of compliance, the municipalities in violation did not treat their wastes but required additional pre-treatment from their industrial sources. The treatment costs to these dischargers was based on flow rates between 50,000 and 100,000 gallons per day.

4. The total cyanide which entered the stream was assumed to degrade or decay according to the following relationship:

$$L_t = L_o e^{-0.12t}$$

This may very across streams, depending upon its characteristics.

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APPENDIX

DISCHARGERS BY SIC WITH AT LEAST ONE CYANIDE SAMPLE EXCEEDING 0.025 mg/ℓ

IEPA Sampling Results - 1974-1975

	Name	Maximum Total Cyanide Concentration (mg/ℓ)
1. SIC 28 Chemicals	Marbon Division	0.12
	B. F. Goodrich	1.40
	Carus Chemical	0.04
	DuPont Lagoons	0.190
	Diamond International	0.080
	Dow Chemical	0.100
	Rexene Polymers	0.050
	Stepan Chemical	0.030
	3M	0.250
	Abbott Laboratories	0.260
2. SIC 29 Petroleum-Based Products	Texaco, Inc. (Lawrenceville)	0.21
	Marathon	0.290
	Union Oil	0.860
	Mobil Oil	0.650
	GAF	0.120
3. SIC 32 Stone, Glass	Libby-Owens-Ford	0.030
4. SIC 33 Steel Manufacturing	Caterpillar Tractor	0.030
	Moline Malleable	0.050
	Wisconsin Steel	0.040
	U.S. Steel (South Works)	0.160
	Interlake	0.065
	Republic	0.060
	Granite City Steel	0.058
	Quality Metal Finishing	0.440
	U.S. Steel (Waukegan)	0.070
5. SIC 34, 35 Metal Treating and Fabrication	Spartan Manufacturing	0.388
	American Nickeloid	0.220
	Aubrey Manufacturing	0.690
	Modern Plating	3.600
	Woodstock Die Casting	0.470
	Caterpillar Tractor	0.050
6. SIC 4911 Power	Commonwealth Edison (Dresden)	0.050
7. Sanitary Districts	Spring Valley	0.030
	Peoria	0.040
	Cuba	0.110
	Mendota	0.050
	East Dundee	0.040
	Elgin (Main S.)	0.800
	West Dundee	0.440

Appendix to Chapter 3 (cont.)

	Name	Maximum Total Cyanide Concentration (mg/ℓ)
7. Sanitary Districts (Continued)	Aurora	0.420
	Fox Fiver Grove	0.162
	Plano	0.030
	Woodstock North	0.300
	Crystal Lake	0.030
	Kankakee	0.080
	Minooka	0.050
	Rockdale	0.405
	Hanover Park	0.040
	Joliet	0.100
	West-Southwest (MSDGC)	0.030
	Calumet (MSDGC)	0.150
	Bloom Township	0.040
	Deerfield	0.030
	Galva	0.130
	Sterling	0.290
	Rockford	0.080
	Amboy	0.040
	Morrison	0.170
	DeKalb (Main)	0.100
	Hampshire	0.040
	Freeport	0.100
	NSSD (Waukegan)	0.040
	NSSD (North Chicago)	0.060

Appendix to Chapter 5

ESTIMATION OF AFFECTED WATER QUALITY SEGMENTS

To evaluate the effects of alternative effluent standards requires an understanding of resulting levels of cyanide and probable flow conditions in the receiving waters. Five standards and their effect on water quality were considered. Probabilities for two stream flow conditions and two cyanide concentrations were calculated and utilized in measuring these effects and their probability of occurrence. For a given flow rate and cyanide quantity, the river cyanide concentration can be calculated and then compared to toxic levels to determine its impact. Therefore, the calculation of impacted river miles was based on ascertaining probable levels of cyanide in five rivers, the Fox, Des Plaines, Little Calumet, Calumet-Cal Sag Channel, and Illinois Rivers.

Because stream flow rates vary independently of cyanide discharges, the probabilities of each are also independent. The joint probability of two independent events occurring simultaneously is the product of each probability. Therefore, the two flow conditions and two cyanide discharge levels represented four combinations, each with its own unique joint probability.

Consider the probability matrix below which depicts these joint probabilities.

Joint Probabilities

	Pr_3	Pr_4
Pr_1	$Pr_1 \times Pr_3$	$Pr_1 \times Pr_4$
Pr_2	$Pr_2 \times Pr_3$	$Pr_2 \times Pr_4$

Pr_1 = Stream flow 10% occurrence
Pr_2 = Stream flow 0.2% occurrence
Pr_3 = Average cyanide discharge
Pr_4 = Maximum cyanide discharge

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Stream flows considered represent a low flow occurring 10% of the time and one with incidence 0.2% (7-day, 10-year low flow). A low flow with a 10% incidence over a long period of time could be associated with an annual probability of 1.0. In other words, it would occur at least once a year, and since a year is our unit of measurement, the probability equals 1.0. The seven-day, ten-year low flow has a 0.2% probability or it occurs once every ten years. Thus, in annual terms the probability of incidence is 0.1 or 10% (Pr_2 = 0.1).

The probabilities associated with the frequency of achieving the average and maximum cyanide levels are taken from the discharge characterizations compiled in Chapter 3. For each river segment, the dischargers are identified and the cyanide values determined.

Typical values for Pr_3 and Pr_4 are 0.5 and 0.05 incidence. Thus, the sample joint probabilities could be calculated as shown below:

P [10% low flow and avg. CN^- level] = $Pr_1 \times Pr_3 = 1.0 \times 0.5 = 0.5$

P [10% low flow and max. CN^- level] = $Pr_1 \times Pr_4 = 1.0 \times 0.05 = 0.05$

P [0.2% low flow and avg. CN^- level] = $Pr_2 \times Pr_3 = 0.1 \times 0.5 = 0.05$

P [0.2% low flow and max. CN^- level] = $Pr_2 \times Pr_4 = 0.1 \times 0.05 = 0.005$